PHOTOVOLTAICS FOR THE GAMBIA – IMPLEMENTATION STRATEGIES FOR RENEWABLE ENERGY TECHNOLOGY TRANSFER

A Thesis submitted in partial fulfilment of the requirements of the University of Northumbria at Newcastle for the degree of Doctor of Philosophy.

By

URIEL ABLE-THOMAS, BSc(Hons), MSc, CEng, MIEE.

Department of Electrical, Electronic Engineering and Physics, Faculty of Engineering, Science and Technology, University of Northumbria at Newcastle in collaboration with the Gambia Civil Aviation Authority, Banjul International Airport, Yundum, The Gambia.

JULY 1994.

ABSTRACT.

This research project has assessed the social and techno-economic aspects of photovoltaic (PV) manufacture and dissemination in the Gambia as an appropriate alternative source of energy for development. The research has also considered the relationship between energy and development, the need to conserve and use fuelwood and to utilise the other conventional energy sources more efficiently.

The Gambia's energy balance has been presented for 1988/89 to 1991/92 indicating its energy demand pattern. The importance of an integrated energy plan has been indicated with the need to conserve and use energy more efficiently.

The project has considered some of the renewable energy technologies that might be appropriate sources of energy for development with emphasis on PV.

The techno-economic benefits of PV lighting, PV water pumping and PV vaccine refrigeration compared to the conventional systems have been assessed. The technical performance, reliability, efficiency and costings have been presented for PV systems compared to existing or potential conventional systems in order to assess their technical feasibilities and economic viabilities.

A specific case study has been investigated into the techno-economic feasibility of installing PV stand alone, diesel or PV/diesel hybrid systems at Banjul International Airport.

Different models of technology transfer to developing countries have been discussed. An assessment has been made of the needs and associated problems for developing countries and the Gambia in particular. The appropriate models and strategy for PV manufacture and dissemination in the Gambia have been identified. Means of transferring these technologies into the Gambia have been suggested.

An assessment of the relevant criteria for the Gambia to acquire the PV technology was carried out. Several levels of acquiring PV technology through technology transfer have been identified. A strategy for acquiring PV technology and the dissemination procedure in the Gambia has been suggested.

COLLABORATING ESTABLISHMENT:-

The Gambia Civil Aviation Authority
Banjul International Airport
Yundum
The Gambia
West Africa.

For the Lord giveth wisdom: out of his mouth cometh knowledge and understanding.

Proverbs 2: 6

This Work Is Dedicated To My Loving Wife And Children.

ACKNOWLEDGEMENTS.

I wish to thank my wife, Jean, and my children Samuel, Susannah and Shola-Bola, for their support, encouragement and patience during the research programme.

I would like to thank all those who helped and encouraged me during my work. I would especially like to thank my Director of Studies, Professor R. Hill for his support, invaluable guidance and highly informative discussions. I would also like to thank my other supervisors, Professor P. O'Keefe and Dr. N. Pearsall, for their guidance, support and valuable discussions. I am grateful to my adviser, Mr. Anthony Derrick of IT Power, for providing me with useful information. My sincere thanks also goes to Mr. Derek Cox of Racal Training Services Limited for supplying me with valuable information pertaining to the navigational aids and communications system at Banjul International Airport.

I would also like to thank my colleagues who encouraged and assisted me in many different ways during the research programme. These include among many others: Dr. R. Miles, Dr. B. Ghosh, Dr. M. Carter, Dr. J. Winckler, Dr. N. Robson, Dr. T. Bhatti, Dr. J. Bates, Dr. F. Adurodija, Mrs. K Kynes, Ms. A. Baumann, Mr. & Mrs. Boa Cuamba, Ms. T. Blewett, Mr. A. Musa, Mr. H. Cui, Mr. S. Duke, Mr. S. Bocking, Mr. M. Hyland, Mr. E. Groake, Ms. A. Wilshaw, Mr. E. Lanceley and Mr. V. Hinksman.

I would like to express my appreciation to all the members of staff at the Research Degrees Section, especially Mrs. P. Wigmore, Ms. A. Fenwick and Ms. M. Davidson for their patience and assistance.

I would also like to thank my brothers, the rest of the Able-Thomas family and all friends and relatives for their immense support and encouragement during the research period in the UK.

I wish to express my gratitude to the Association of Commonwealth Universities for their sponsorship and the British Council for administering the award.

I would finally like to express my gratitude to the Board of Directors, the Director General and co-workers of the Gambia Civil Aviation Authority for their support during my study leave period.

CONTENTS PAGES

LIST OF FIGURES

LIST OF TABLES | PAGES

LIST OF ABBREVIATIONS

AC = Alternating Current.

ACON = Air Conditioner.

ALCC = Annualised Life Cycle Cost.

a-Si = Amorphous silicon.

ATAS = Advance Technology Assessment System (UN publications).

BEMS = Building Energy Management System.

BIA = Banjul International Airport.

BOS = Balance of System.

BP = British Petroleum.

BCU = Battery Control Unit.

Ca = Annual payment or benefit.

Comms = Communications System.

CdS = Cadium sulphide.

CdTe = Cadmium Telluride.

CIF = Cost Insurance & Freight.

C_R = Reserve Capacity of battery.

Cr = Future cost or benefit for a period of N years.

$CuInSe_2$ = Copper Indium Diselenide.

Cu_2S = Copper sulphide.

CZ = Czochralski process.

D = Battery's fractional depth of Discharge.

d = Discount rate

DANIDA = Danish International Development Agency.

DC = Direct Current.

DEC = Diesel Energy Cost.

DME = Distance Measuring Equipment.

DVOR = Doppler VHF Omni Range.

ECH = Energy Cost of Hybrid System.

EG-Si = Electronic Grade Silicon.

EPI = Expanded Programme on Immunization.

ERP = Economic Recovery Programme.

EVA = Ethylene Vinyl Acetate.

FDI = Foreign Direct Investment.

FF = Fill Factor.

f_d = Fraction of diesel energy cost.

f_p = Fraction of PV energy cost.

GAMTEL = Gambia Telecommunications Company.

GCAA = Gambia Civil Aviation Authority.

GCUL = Gambia Cooperative Union Limited.

GDP = Gross Domestic Product.

GGFP = Gambia-German Forestry Project.

GREC = Gambia Renewable Energy Centre.

I = Current.

i = Inflation rate.

ICAO = International Civil Aviation Organisation.

IEC = International Electro-technical Committee.

I_L = Load current.

ILO = International Labour Organisation.

Im = Current at maximum power point.

IMF = International Monetary Fund.

ITC = International Trypanotolerance Centre.

Iph = Photocurrent.

Isc = Short Circuit Current.

k = Boltzmann constant (1.38×10^{-38} JK^{-1})

LCC = Life Cycle Cost.

LPG = Liquid Petroleum Gas.

MSG = Management Services Gambia Limited

MG-Si = Metallurgical Grade Silicon.

MNC = Multi-National Company.

MTBF = Mean Time Between Failure.

NGO = Non-Governmental Organisation.

Navaids = Navigational aids.

NTIS = National Technical Information Services (American Government Publications).

NCP = National Convention Party.

Nb = Battery efficiency.

Nbcu = BCU efficiency.

Ninv = Inverter efficiency.

Nm = Matching efficiency.

OECD = Organisation for Economic Cooperation and Development (formally OEEC = Organisation for European Economic Cooperation).

OM = Outer Marker.

Pa = Annual PW factor.

PV = Photovoltaics.

PSD = Programme for Sustained Development.

Ppk = Peak power of solar generator in kW.

PPP = People's Progressive Party.

Pr = PW factor for a period of N years.

PEC = PV Energy Cost.

PW = Present Worth.

q = Electronic charge (1.6×10^{-19}C)

R&D = Research & Development.

R/F = Radio Frequency.

R_L = Load resistance.

Rx = Receiver.

SAND = Sandia National Laboratories, Albuquerque, NM.

SAPV = Stand-Alone PV system.

Si = Silicon.

SG-Si = Semiconductor Grade Silicon.

T = Temperature in Kelvin.

TE_p = Total energy produced by PV system.

TE_d = Total energy produced by diesel system.

TIM = Transparent Insulation Material.

TT = Technology Transfer.

Tx = Transmitter.

UCL = UHF Communications Link.

UHC = Utilities Holding Company.

UHF = Ultra High Frequency.

UNCTAD = United Nations Conference on Trade & Development

UNESCO = United Nations Educational Scientific and Cultural Organisation.

UNITAR = United Nations Institute for Training & Research

UNSO = United Nations Sahelian Office.

USAID = United States Agency for International Development.

UWC = Unit Water Cost.

V = Voltage.

v = Voltage across depletion region.

VHF = Very High Frequency.

Vm = Voltage at maximum power point.

Voc = Open circuit voltage.

Wel = Electrical energy demand in kWh per day.

Wr = Radiated solar energy in kWh per m^2 per day.

WHO = World Health Organisation.

GLOSSARY

Annualised Life Cycle Cost (ALCC) = The total lifetime costs of a system expressed as a sum of annual payments.

Annualised Present Worth = The annual value of a future cost or benefit expressed in present day money.

Balance of System (BOS) = Parts of a PV system other than the array.

Capital Cost = The cost of installation, including design costs, land costs and other costs necessary to build a facility. This does not include operating costs.

Czochralski Process (Cz) = Method of growing a crystal of large size by slowly lifting a seed crystal from a molten bath of the material under careful conditions of cooling.

Discount Rate (d) = The opportunity cost of making an investment.

Inflation Rate (i) = The increase in the general price level as a percentage of the previous year's prices.

Lifetime = The maximum period during which an investment facility can be used for either production or other purposes.

Life Cycle Cost (LCC) = The total lifetime costs associated with a system expressed in terms of present day money.

Present Worth (PW) = The value of a future cost or benefit expressed in present day money.

Photovoltaics (PV) = The process of direct conversion of light into electrical energy.

Salvage Cost = The value of material assets connected with an investment project, consisting of their initial investment costs minus the depreciation up to a certain point in time (usually the service life).

~ = Approximately.

CHAPTER 1

1.0 INTRODUCTION.

The aim of this research programme was to study and analyse the technical and socio-economic issues which determine the extent of dissemination of photovoltaics (PV) in the Gambia for sustained energy development. These critical analyses will enhance the proposal of a strategy for accelerated diffusion of PV in the Gambia. PV is the process of direct conversion of light into electrical energy.

A staggering 45% of all foreign exchange earnings of the Gambia is used for the importation of petroleum products. Despite these huge imported energy bills, the overall energy balance is heavily weighted towards fuelwood. Fuelwood accounted for well over 68% of all energy consumption in the Gambia during 1991/92 and this figure is apparently on the increase. The heavy dependence on the supply of fuelwood puts great pressure on the Gambian forest which is constantly being depleted of its trees. Efforts should now be directed to reducing this pressure by looking at alternative sources of energy like renewables, increasing the reforestation to consumption ratio and using energy efficiently. The Gambia has an alarming population growth rate of 4.1%. The aim and achievement of a short and long term development objective requires that energy resources of the proper type and magnitude should be available to sustain the various sectors of the Gambian economy. This makes the need for appropriate renewable energy policy intervention and implementation strategy more urgent. In order to halt this dangerous environmental and socio-economic degradation, countries like the Gambia need fundamental changes to the way their biomass energy and economic base are being eroded. There is an urgent need to investigate areas in which renewable energy and PV in particular could be used in supplementing the energy needs of the Gambia.

The Gambia's geographic location endows the country with abundant sunshine. It receives an average daily radiation of 5.5 kWh/m^2. There are opportunities for far reaching applications of PV technology, i.e. electricity produced by PV can operate water pumps for drinking and irrigation, power loads such as refrigerators, communications system, radios, television, light bulbs, etc. There is potential for using wind pumps in areas with wind speeds of 3 m/s or greater. Other potential renewable energy technologies that could be beneficial to the Gambia are:- energy crops, agricultural residues, peat, biofuels, draught animals, passive solar energy and hydropower. All of these potential renewables are being under-utilized, hence the need for increased exploitation in meeting the future energy needs of the nation.

The research has looked at different renewable energies that might be appropriate for the Gambia with particular emphasis on PV. While the cost of some fossil fuels has increased, developments in renewable energy in the 1970's through to the 90's, particularly in solar, wind and biomass energy have led to remarkable cost reductions in these technologies. There is now a growing awareness that renewable energy is an abundant resource which can be harnessed. Most of the renewables considered are more environmentally friendly and cleaner form of energy generation than fossil fuels.

The research has looked at the PV technology that is most appropriate for the Gambia. Appropriate PV technology in this context includes a technical appraisal of PV systems, study of the needs of the Gambia which could be met by PV and the techno-economic appraisals of PV in comparison with other energy sources to determine the cost effectiveness of PV in each particular case.

The Gambia Civil Aviation Authority (GCAA) have navigational aids and communication equipment at remote sites. The operating cost of maintaining these diesel generators is proving to be extremely expensive and unbearable. Replacing these diesel generators with PV could be found to be cost-effective, since it needs little operating and maintenance cost. A specific case study has been carried out, assessing the reliability and cost-effectiveness of installing PV generators to replace the conventional generators powering the navigational aids and communication system at Banjul International Airport. The study has investigated the benefits of replacing the diesel generators by PV stand alone and PV/diesel hybrid systems.

A critical appraisal of PV deployment in the Gambia has been performed. It has considered the supply and maintenance requirements for a full dissemination of PV systems. Also considered are three other issues: first, the need for training of maintenance personnel, secondly, the possibilities of manufacture of PV systems or system components in the Gambia, and thirdly, the organisational changes needed to facilitate the dissemination of PV. The benefits to the individual users have been quantified as far as possible, with a critical assessment of the benefits of investing in PV compared to conventional systems.

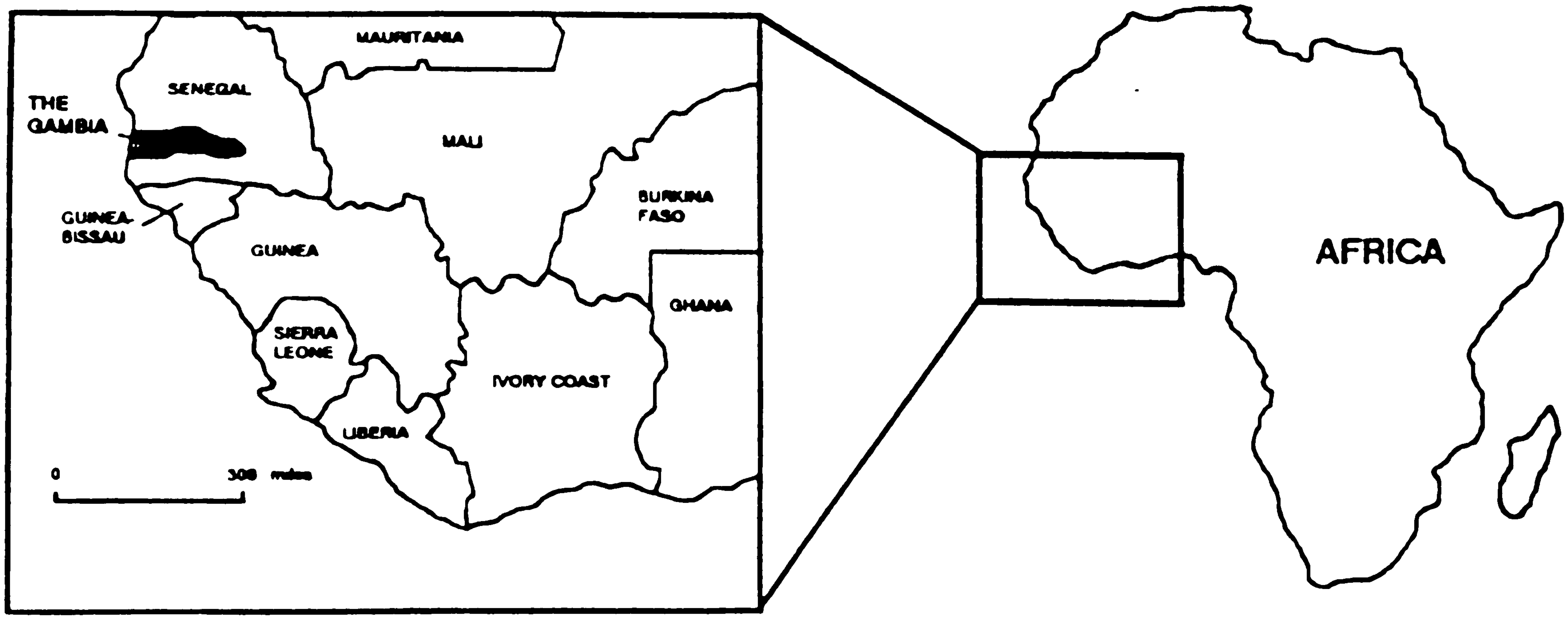
For the Gambia to develop and build up a solid technology base, it must have access to modern technology transfer. To acquire this, there are basically two approaches: first, by spending an enormous amount and time on research & development (R&D) to invent and produce its own technology, or, secondly, to negotiate with those who own the technology and to import it for future adaptation through technology transfer. The Gambia, as a late starter in modern technology, has the advantage of having access to technology through technology transfer. As a result of this, the Gambia, in its drive to raise its overall level of technological know-how, can take full advantage of the flow of technology through different models, at predictable cost. The thesis will discuss the different models of technology transfer, and assess the needs and its associated problems. It also assesses the conditions for the Gambia to acquire PV technology, looking at the relevant criteria such as capital and human resources availability, industrial infrastructures and educational environment. The appropriate model and strategy for PV manufacture and dissemination in the Gambia will be identified and suggestions made for the means of transferring these technologies into the Gambia in order to create an indigenous capability in PV.

1.1 GEOGRAPHY OF THE GAMBIA.

The Gambia, with a population of 1,025,867 in 1993, which is growing at an annual rate of 4.1%, is situated on the West African coast, midway between the Tropic of Cancer and the Equator, at latitude 13.5^{o}N and longitude 13.5-17^{o}W. Figure 1 shows the location of the Gambia on the continent of Africa. The weather is subtropical with distinct dry and rainy seasons. From the end of October to the end of May, the harmattan Sahara winds result in the dry winter season, with little or no rainfall and daily sunshine. During the harmattan and summer periods, the temperature and humidity ranges from 19-27^{o}C, 30-60% and 27-32^{o}C, 60-85% respectively. The average daily solar radiation is 5.5 kWh/m^2.

The Gambia is one of the smallest countries but has the longest river (the river Gambia) in the West African region. The winding of the Gambian river stretches 300 miles from the Atlantic coast through the Gambia and is bounded by its neighbour Senegal in the north, east and south. The actual borderline was laid out by the British and French colonial rulers.

Figure 1.1 Map showing location of the Gambia.



The Gambia has an area of 11,295 km^2, of which 948 km^2 are river area, and it extends inland at widths varying from about 24 to a maximum of 64 km along the banks of the river Gambia. The river Gambia makes a strong imprint on the landscape and has looked upon as a sign of fertility in days gone by. Moreover, Gambia's moist areas make it an important frontline against the ever increasing expansion of the desert in the Sahel area.

1.2 AGRICULTURE.

The principal crops produced are:- peanuts, millet, sorghum, rice, corn, cassava and palm kernels. Other agricultural products are livestock in the form of cattle, sheep & goats, forestry and fishery. The fishing resources are yet to be fully exploited.

Most farmers depend for the greater part of their income on groundnuts, which are sown in June and July and harvested in October and November.

1.3 GOVERNMENT.

The Gambia achieved independence from Britain in 1965 under Sir Dawada Kairaba Jawara and has since been a multiparty democratic country. It has a parliament that is elected every five years by a universal adult suffrage of twenty-one years and above. The President appoints a Vice-President to lead the Government in the house of Parliament and a Cabinet of ministers. The main political parties are the People's Progressive Party (PPP) and the

National Convention Party (NCP). The leading party in government is the PPP headed by President D.K. Jawara and the main opposition party is the NCP lead by the Honourable S.M. Dibba.

1.4 THE ECONOMY.

The Gambia has no important mineral resources. It has very limited other natural resources but has abundant solar energy resources, average wind energy resources and some water energy resources. The economy is largely based on agriculture, the cultivation and export of groundnuts being the mainstay of the economy. It has a Gross Domestic Product (GDP) per capita of about $230 (1992). Agriculture engages about 75% of the population which includes small-scale manufacturing activities like processing groundnuts, fish and hides. Tourism is a growing industry and it is playing an important role in the economic development of the country. It has helped to improve the foreign exchange earnings of the country but it is an industry that the Gambia cannot afford to rely on for continued economic development.

In the Gambia, farmers are taking advantage of the government's efforts to diversify the economy and reduce the reliance on groundnuts. The construction of access causeways into swamp and mangrove areas, draught animals and tractor ploughing, training programmes and demonstration plots have convinced the farmers of the value of rice cultivation. With the example of projects such as the Jahally-Patcharr rice farms situated near

Georgetown and the rice station at Jenoi, a spectacular expansion of rice cultivation has taken place since the 2nd World War. Rice is now the principal food crop in most of the Gambia and is being grown as a secondary cash crop.

During the decade following independence in 1965, macro-economic conditions were broadly stable and growth rates were appreciable. From 1975 to 1985, however, there was a marked deterioration in economic performance, due to a combination of external shocks and inappropriate domestic policies. External imbalances prevailed side by side with internal disequilibrium. An expansionary fiscal policy and an over-valued exchange rate encouraged imports while contributing to the run down on external reserves, a build-up in external indebtedness and a worsening of the balance of payments deficit. These imbalances were reflected in the economy in the form of a low output growth and an acceleration of inflation. By 1985/86, the economic situation had grown worse, external reserves were depleted to less than one week of import cover and the external public debt was 113% of GDP, the current account deficit was about 30% of GDP and the budget deficit stood at 10.2% of GDP. The necessity of an economic adjustment became more apparent.

The Economic Recovery Programme (ERP) was launched in the middle of 1985 specifically to address this deteriorating economic situation by restoring financial equilibrium and laying the foundation for a sustainable growth. The implementation of the ERP was very successful. The thrust of the Government's adjustment strategy was to eliminate exchange rate and price distortions, restrain public expenditure, deregulate the banking system, etc. Overall, the ERP helped to stabilize the economy and restore confidence. Economic activity picked up remarkably, GDP/year registered an average growth rate of 4% in the four years to 1993. Exchange rates stabilized, foreign currency transactions expanded in volume and inflation declined from 76% in June 1986 to about 6% in June 1993 and 1.8% in March 1994. Also, accumulation of gross official reserves stood at five months of import cover. The achievement of a general macro-economic stability is, however, not a ticket to prosperity. The government decided to take further steps in order to ensure the continued improvement of the economic situation. At the expiration of the ERP period in 1990, the Programme for Sustained Development (PSD) was instituted. While maintaining the thrust of the objectives of the ERP, the PSD was aimed at intensifying the efforts to stimulate private sector development.

The Gambia Government's policy of providing a stable macroeconomic environment conducive for foreign investment entry, liberal trade policies, the promotion of private ownership and minimisation of direct participation of the state in economic activity has contributed to the country's continued economic growth. It also has a liberal foreign exchange policy, hence the exchange control act, which was suspended in 1986, was repealed completely in 1992. Furthermore, the Gambia has accepted the conditions of Article VIII of the International Monetary Fund's (IMF) articles of agreement. This implies that the Gambia has formally accepted the elimination of all restrictions on current international transactions. The exchange system in the Gambia is so liberal that restrictions do not exist on even capital transactions.

Despite these economic successes, the Gambia imports all its fossile fuel, about 33% of its food and most manufactured goods. This has created a dynamic impetus to solve the critical energy situation of the country.

1.5 STRUCTURE OF THE THESIS.

The subsequent chapters of the thesis are structured as follows:-

CHAPTER 2 - ENERGY & DEVELOPMENT.

Chapter two discusses the key realities of the relationship of energy, development and economic growth, the continuing reliance on biomass fuel, the need to increase reliance on indigenous renewable energy sources and the necessities of an integrative energy policy.

CHAPTER 3 - ENERGY BALANCE OF THE GAMBIA.

Chapter three analyses the Gambia's energy balance, looking at energy consumption from an enduse perspective. The enduse analysis looks at the major energy consumption sectors and then tries to identify areas where renewables could provide more efficient energy services.

CHAPTER 4 - ROLE OF RENEWABLE SOURCES OF ENERGY.

Chapter four describes the function of some renewables that could be an appropriate source of energy for development in the Gambia.

CHAPTER 5 - PV FOR HOUSEHOLD & COMMUNITY APPLICATION.

Chapter five discusses some PV applications that are technically and economically beneficial to the Gambia. Technical performance, reliability and cost estimates have been assessed for the following:-

(1) PV lighting system for domestic and educational use,

(2) PV water pumping system for domestic and agricultural uses and

(3) PV medical vaccine refrigeration system.

CHAPTER 6 - PV FOR HIGHVALUE ADDED ACTIVITY.

Chapter six provides an economic case study of PV, diesel and PV/diesel hybrid system for powering telecommunications and navigational aids at Banjul International Airport in the Gambia.

CHAPTER 7 - TECHNOLOGY TRANSFER TO DEVELOPING COUNTRIES & ASSOCIATED PROBLEMS.

Chapter seven defines technology transfer, discusses different models of technology transfer and assesses its needs and associated problems.

CHAPTER 8 - STRATEGY FOR ACCELERATED DIFFUSION OF PV IN THE GAMBIA.

Chapter eight assesses the relevant criteria for the Gambia to acquire PV technology. It identifies and put forward proposals in obtaining a successful PV dissemination in the Gambia.

CHAPTER 9 - SUMMARY & CONCLUSION.

Chapter nine contains the summary and conclusions of the research programme.

CHAPTER 2

2.0 ENERGY AND DEVELOPMENT.

This chapter will discuss the key realities of the relationship of energy, development and economic growth, the continuing heavy reliance on traditional fuels, the necessity of an integrative energy policies, reducing the dependence on crude oil imports and increasing the reliance on indigenous renewable energy sources. The achievement of near and long term development objectives requires that energy resources of the proper type and magnitude be available to sustain the various sectors of the Gambian economy. As the population increases, with increased depletion of indigenous natural resources and with increasing constraints on the availability of high quality agricultural land, the need for appropriate energy policy intervention becomes increasingly urgent.

2.1 INTRODUCTION.

People need energy to grow and prepare food, to build, heat and light their houses, to keep industry working and to keep transport on the move. In all these activities, the need for energy arises from the basic fact that, in one way or another, they all involve "moving things", and that means transferring energy to them. The energy needed for such processes has to be available in a convenient form.

Throughout most of the history of human society, energy needs have been met very largely from immediately available, and essentially "renewable", energy sources such as wood, solar, wind and water. Since the industrial revolution, however, social production of goods, services and amenities has been based upon a rapid growth in the demand for energy and this demand has up till now been met almost entirely from "stored energy sources" in the form of fossil (i.e. coal, oil and natural gas) and nuclear fuels. The problem is that fossil and nuclear fission fuels are not renewable and so the world's limited energy capital is rapidly being depleted. Moreover, conventional sources, unfortunately, have environmental problems such as pollution of the atmosphere with dangerous green-house or acid gases like oxides of carbon, sulphur and hydrocarbons which may result from the combustion of fossil fuels.

The most significant of all is carbon dioxide (CO_2) which is a by-product of the combustion of fossil fuels. Atmospheric CO_2 influences the climate via the so called green-house effect, the cause of global warming. Carbon dioxide absorbs heat radiation from the earth's surface, trapping it and preventing it from dissipating into space. The resulting temperature increase could produce changes in rainfall patterns, geographical shifts in areas suitable for food production and areas sensitive to desertification, higher sea levels due to the melting of polar ice, and changes in fish stocks, forests, and water supplies. These changes could have profound social, economic and political impacts on a global scale. Another by-product of our energy usage is aerosols (i.e.

suspensions of solid or liquid particles in the atmosphere). Aerosols influence climate because they alter the energy exchanges between the sun and the atmosphere and between the atmosphere and the ground. Nuclear fuels also have environmental hazards because of the danger of radioactive materials to human health.

In recent years the cost of imported fossil fuels has been putting an added economic burden on the developed as well as the developing countries of the world; although this burden is great for the industrialised nations, it is even greater for emerging countries. In their earnest desire to solve the energy crisis, many of the developing countries are now turning to appropriate renewable energy sources such as solar energy to meet their urgent needs. Most developing countries have been prevented from meeting these energy needs by a lack of funds and properly coordinated infra-structural network for a proper dissemination of renewables. The energy crisis is the most serious crisis that emerging countries are encountering as their financial, economic and industrial planning and development have been critically retarded, not only by the ever-increasing energy bill, but also by the lack of development of adequate renewable energy resources within their own boundaries.

Governments of developing countries have pinpointed a number of areas of prime importance to ensure economic growth, such as health, education, agriculture etc. In most cases, PV can play a very important role, since the majority of the population live in rural areas where conventional forms of power are very costly and not readily available.

The Gambia has an insufficient electricity generating capacity in the major towns and cities and, frequently, no power supply in rural areas. An appropriate way of meeting these energy needs is to use PV since sunlight is plentiful, available almost 7 to 10 hours a day, 365 days per year. Electricity produced by PV can light homes and streets, power loads such as refrigerators for domestic and medical uses, telecommunications systems and navigational aids, water pumps for drinking and irrigation etc, at lower cost than some conventional energy sources.

The environmental cost of conventional generators in the long term could be extremely great taking into consideration the harm done to present and future generations. It must be a wise decision to invest in a clean form of appropriate energy generation. The importation of fuel is a financial burden, which naturally available renewable energy like PV could help to reduce. Investing in this technology could make future savings on badly needed foreign exchange earnings.

The application of PV in the rural and urban areas in the Gambia is proving to be both technically and economically viable. Despite this technical and economic success, dissemination has been rather slow because of other technical, social, political and financial factors, lack of funds and management of energy sources being the main hindrances.

2.2 BIOMASS FUELS.

A worsening trend of over-consumption of what is still the developing world's most important energy resource, fuelwood, is leading to an agricultural and/or ecological crisis of perhaps unprecedented dimensions.

Fuelwood and charcoal are the energy sources used by the majority of Gambians in both urban and rural areas. Fuelwood is generally preferred in rural areas, mainly because it is obtained free. Charcoal is preferred in towns on account of its being easy to transport, distribute and store. It is almost smokeless and has a higher calorific value (30 MJ/Kg) than fuelwood (15.5 MJ/Kg), i.e. the energy content of charcoal is about twice that of fuelwood [1].

The most predominant use of wood in the Gambia is in the form of firewood and charcoal, mainly in household cooking, ironing and heating. Charcoal is produced using simple earth mound or pit kilns, with conversion efficiencies ranging between 10 and 20% [2]. The charcoal produced is used in traditional cookstoves with rather poor heat transfer efficiencies (15-18%) [2]. Similarly, firewood used directly in traditional fireplaces delivers less than 10% of the primary energy contained in firewood [2][3]. Although stoves and kilns are inefficient, other factors are involved in the poor utilization of fuelwood. These include insufficient drying of firewood, non-uniformity of charcoal, poor handling of charcoal resulting in too many unusable fires, and lack of a mechanism to extinguish fires after use. The development and diffusion of charcoal conversion and utilization technology can therefore make an appreciable contribution to the management of wood energy demand in the country. A number of improved charcoal stoves and improved kilns projects have been initiated. Efforts have centred around the design and production of double-walled all metal stoves, metal ceramic stoves, and the dissemination and popularization of the half-orange and Cassamance charcoal production kilns.

2.3 FUELWOOD CONSUMPTION AND DEFORESTATION.

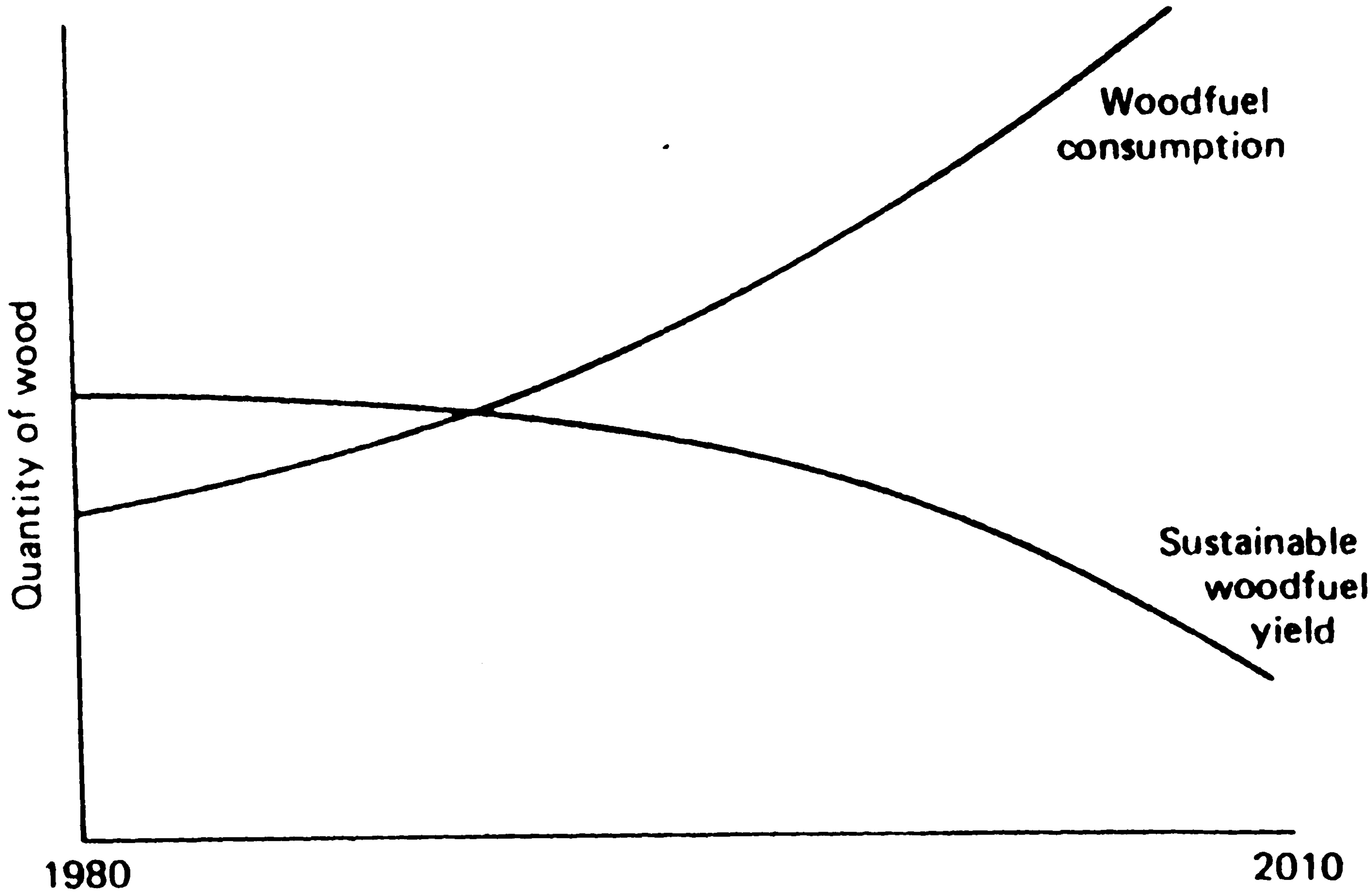
The cutting down of trees to be used as fuelwood is widely believed to be the main cause of the deforestation taking place in many parts of the developing world. There is an apparent image of rural fuelwood collectors bringing an energy crisis on themselves by cutting the forest resources on which they depend for fuel. Such an impression is generally exaggerated. In most countries the major part of the wood used by rural domestic consumers does not come from forests; it comes from their immediate surroundings. Nor is it usual for people to cut whole trees to meet their fuelwood needs. They much prefer to collect dead wood because it is dry, lighter to carry and easy to burn.

Pressure comes on forest resources for a variety of reasons. Sometimes, as happened in the Sahel region during the 1970s and 1980s, droughts ravage large areas of woodlands, killing a huge number of trees. Also around cities, there are areas of concentrated cutting to supply the urban fuelwood market. However, by far the most common cause of forest destruction is the clearing of land for growing food.

Population growth, migration, war and drought are driving impoverished people in many developing countries to move into woodlands and forest areas and clear them of trees in order to farm the land. Initially, there may even be a surplus of wood because of tree felling. But, inevitably, there comes a time when there is not sufficient fuel to meet everyone's needs. The women, who remain responsible for supplying their families with fuel, now have to walk further and search longer for what they need. In places they can be seen cutting branches from living trees. To the outsider, it may look as though they are causing the shortage that is afflicting them. In fact, they are its helpless victims.

Fuelwood, which supplies the majority of the energy needs of the developing world, is a renewable energy source. The irony is that it is running out. Taking the developing world as a whole, there is no doubt that fuelwood resources are being depleted considerably faster than they are being renewed. Figure 2.1 illustrates the general trend of the quantity of available wood against the fuelwood consumption per yield. The actual quantities involved and the dates will vary according to the particular circumstances in regions where people rely on

Figure 2.1 Schematic representation of the fuelwood "crisis" [16].



fuelwood for their energy needs. This deteriorating situation of the widening gap of supply and demand for fuelwood provoked a call for massive tree growing programmes throughout the developing world.

2.4 RURAL TO URBAN ENERGY SHIFT.

Historically, development has been associated with urbanization. In the Gambia, the proportion of the population in the rural areas has been on the decrease and it is expected to decline for a while. Urban incomes are reported to be over four times those of rural areas [4]. Consequently, the rural to urban drift and the urban population growth rate are high [5]. The rapid growth of the urban population is profoundly affecting both the national energy balance and the physical environment. The demand and supply of commercial energy is heavily geared towards the urban sectors.

This spectacular growth of the urban population has introduced a distinct character in urban energy use patterns. The preference of the bulk of the urban population for traditional fuels has led to the increasing commercialisation of fuelwood supplies. Increases in income levels have led to shifts in energy usage patterns from fuelwood to non-renewable fuels, such as kerosene and gas. Rapid urban growth has led to an increase in energy demand for transport from rural to urban and within urban areas. It has led to the growth of small, informal industries within the urban areas. An increase in the purchasing power of people has resulted in shifts in fuel choice and patterns of energy demand. This rapid rural to urban growth has led to the growth of sprawling housing estates in the urban peripheries.

Its has been projected that a 1% increase in urbanization could lead to a 12.5% increase in electricity consumption, 14% increase in petroleum consumption and 8.5% increase in fuelwood consumption [6]. Urbanization leads to a marked rise in national energy needs.

Urbanization plays a critical role in economic development as rural emigrants leave their homes in search of better employment opportunities in urban areas [7]. These cities amass large pools of labour, providing low wage labour inputs for the initial stage of industrial development and the subsequent creation of more jobs. In order for this process to advance, urban centres must be able to supply basic needs (food, water, shelter and increasing energy) as well as the means to generate a sufficient level of local income to purchase or finance these goods and services. Although urbanization is closely intertwined with the process of industrialization, in many of today's developing countries urbanization has occurred without industrialization [8]. In Western European development, the two processes occurred simultaneously [9].

2.5 NEED FOR ENERGY POLICIES.

The needs are clear and overwhelming: to provide three-quarters of mankind with enough energy for a decent life. The solutions cannot follow any set prescription; diversity of resource endowment, environmental, demographic, cultural, economic and political conditions will force each developing nation to pursue a specific path.

Although the cooking fires of the developing world have always been limited to the energy sources available from the immediate environment, a major alteration is presently occurring in the traditional system. As the population is increasing at a fast rate, firewood is being consumed more rapidly than it is being regrown in many areas. A vicious circle results, in which it is necessary for each family to devote more of its time and labour to search ever farther away from its home for fuelwood. As tree cover is at first badly affected and then eliminated entirely, vast areas of topsoil are left exposed to rain and wind.

Erosion of the topsoil, especially in mountainous regions, not only contributes to the silting of waterways and eventual flooding downstream, but also accelerates the loss of the land productivity. This effect is further exacerbated by the increased tendency to burn dung where firewood is scare, dung that formerly served as a vital soil fertilizer. In other words, because of an increasing lack of traditional fuel sources and an inability to afford the purchase of commercial alternatives, the energy situation of the poorest people in the developing countries is actually declining, and they are simultaneously undermining their ability to produce their own food.

To halt this dangerous environmental degradation, to expand their food production, and to support serious economic modernization drives, developing nations need to change fundamentally the way their renewable biomass energies are being depleted.

Within the context of social goals regarding provision of basic needs and environmental considerations, energy issues emerge as key components of overall economic development. Energy is a crucial input into the development process. In order to facilitate national development, the articulation of energy development goals and objectives is important, as is the process leading to the evolution of national energy policy. The principal energy policy goal should be to enable the essential social and economic service of energy provision to support the implementation of national social and economic policies and plans. A central concern remains the fact that the Gambia is wholly dependent on imported supplies of oil.

Although petroleum does not account for the largest share of final energy consumption, petroleum imports account for a substantial 45% of foreign exchange earnings. The overall Gambian energy balance is weighted heavily towards biomass use. As a result, the minimisation of biomass use and reforestation in order to reduce and reverse deforestation and its ecological and social consequences are also important aspects of the national energy policy. The major objective of the policy can be summarized as:-

(i) provision of the continuity and security of energy supplies;

(ii) minimisation of energy price fluctuations in order to contribute to general price stability, through strengthening and rationalization of energy supply sources, infrastructure provision and maintenance of a rational energy pricing structure;

(iii) investment in appropriate human resources for energy sector management and energy technology development;

(iv) reduction in the pace of fuelwood depletion through the evolution of more appropriate land management practices and more efficient wood technologies;

(v) widening of access to the electricity system to aid increased productivity;

(vi) improvement of the efficiency of fuelwood conservation and use;

(vii) increase in the efficiency of road transport and energy uses.

The above stated energy policies could help alleviate the increasing energy demand on the economy.

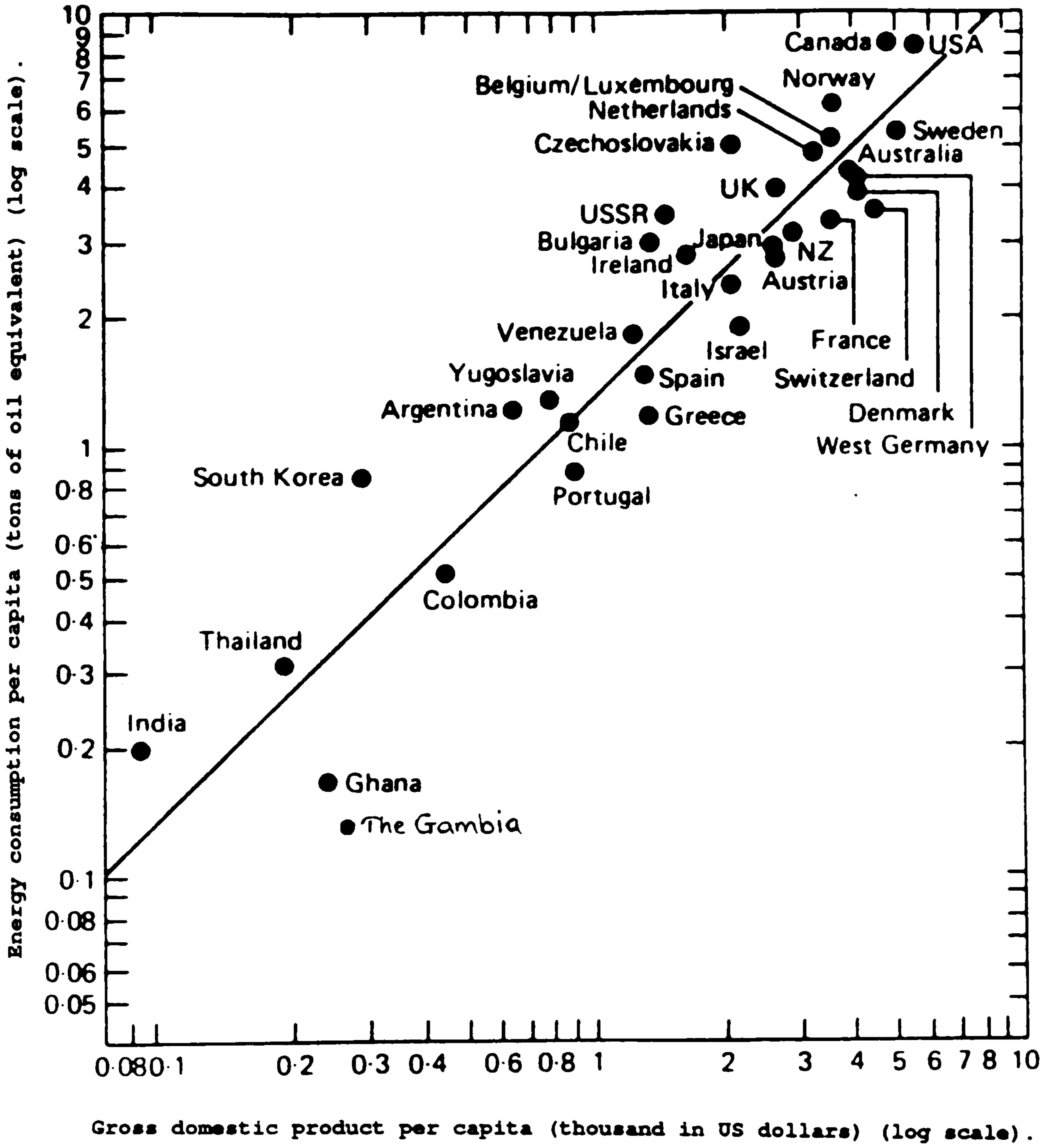
2.6 ENERGY AND ECONOMIC GROWTH.

Any form of relationship between energy consumption and economic growth will have both political and social implications. Figure 2.2 illustrates Gross Domestic Product (GDP) and energy consumption per capita for a large number of countries [10]. It can be observed from figure 2.2 that a broad relationship does exist, the higher the energy consumption per capita, the higher the GDP. It is worth noting that countries with the highest income levels, such as the USA, Canada and Sweden, are also among the top energy consumers. At the other end of the scale, the low income countries, such as India, Ghana and The Gambia, are also very low consumers of energy. The non-commercial energy used by subsistence farmers and part of the population is excluded from the figures, but this makes little difference since their contribution to GDP is also small.

There are complex and diverse reasons for intercountry differences in energy consumption versus GDP. This is mainly due to geographical, industrial, economical, social and political characteristics of countries, which make reliable generalizations almost impossible. A country that has a great deal of heavy industry will have a high energy intensity (energy consumption per unit) of GDP, whilst another country relying on light industries and financial services will have a much lower energy intensity.

The energy utilization characteristics of individual countries are commonly considered to provide an indication of their level of economic development. As a country's economy evolves, its energy requirements will increase. The efficiency with which energy is used

Figure 2.2 Energy consumption per capita versus GDP for selected countries [17].



characterizes the level of development of different societies. One of the principal goals of the Gambia Government is to reduce dependence upon imported petroleum fuel and increase dependence on indigenous renewable energy sources like photovoltaics (PV) [11].

2.7 SUSTAINABLE DEVELOPMENT.

Although the term "sustainable development" means different things to different people, it is stated in reference [12] that "sustainable development builds development strategies to manage natural resources so that they provide for the needs of today while ensuring the resources of tomorrow".

Two major facts dominate the energy scene for the developing world. Firstly, it is clear that energy consumption must continue to grow if development is to proceed and if rural poverty and deprivation are to be alleviated [13]. Secondly, it is equally evident that traditional and conventional approaches to energy supply have a limited future and need to be re-evaluated to ensure short term survival and establish long term energy viability. Usually, rural development takes place with the inefficient use of traditional fuels such as wood, dung and charcoal gradually being replaced by the inefficient use of commercial fuels including kerosene, bottled gas and oil [14]. There is a necessity, as never before, to maximise efficiencies at every stage of energy transition and to find the most appropriate path for the developing countries at each level of their development.

However, large improvements in living standards can be made with little increase in energy use if planners take advantage of cost-effective opportunities to use energy more efficiently. For a wide range of energy-using technologies, saving energy will require less capital investment than supplying an equivalent amount by conventional means, freeing up scarce capital for other purposes [15]. The Gambia, being an energy-importing country, has considerable difficulty controlling its balance of payments. A decrease in energy consumption by its conservation and/or efficient use, yields a monetary flow that can be used for obtaining foreign material like photovoltaics for domestic production of energy and the investment eventually generates other energy and monetary savings. However, this "virtuous circle" is almost impossible to start because of the scarcity of financial resources.

It is important to look at the need to emphasize the local management of natural resources and to generate sustainable energy economy policies which are based on a long-term perspective, primarily deploying appropriate renewable energy technologies like PV. The developing countries' energy requirements will ultimately have to be met by the development of local, indigenous resources. Although there must be immediate financial and technical help to overcome the short-term energy needs, long-term and stable energy supplies will only be achieved with greater emphasis on self-sufficiency. There is a need to address the population growth in relation to the available resources for sustainable development through mass awareness programmes.

2.8 CONCLUSION.

An overview of energy and developmental issues has been presented for the Gambia. In terms of commercial energy demand, the dependence on imported petroleum in an economy starved of external earnings is an important feature of the Gambia's energy system. The continued reliance on traditional biomass fuels is a problem in some areas of the country at present. In the future, fuelwood shortages will be more widely spread unless households begin switching to efficient modern fuels.

An integrated energy plan must be developed, if serious impending crises are to be avoided. The wood resource requirement is expected to increase annually. Oil imports will also increase with a corresponding pressure on foreign exchange earnings, where oil cost against export earnings is increasing at a fast rate.

Serious shortfalls of fuelwood supplies to meet household and other sectoral requirements would cause serious disruptions in the economy and lives of the Gambian people, particularly in the rural sector. Fuelwood scarcity conditions would undermine rural stability and development, increasing rural-urban migration beyond levels which can be sustained by the growth of the urban sector, which itself would be hurt by fuelwood shortages and oil import requirements. Beyond the potential shortages themselves lies the prospect for depletion of substantial portions of naturally occurring stocks of woody biomass, with possible negative consequences for the soil ecology of most of the Gambia's arable lands. This would make efforts to increase food and export crop production, so essential for development, exceedingly difficult.

There is an immediate need to commence a programme of development which must be part of an integrated economic, food and resource planning process. The widening gap between fuelwood requirements and supplies could be halted and even decreased by reducing the end-use requirements through efficiency improvements and increasing the recurrent resource base through fuelwood enhancement schemes. Fuelwood is expected to play a large role in the sustainable energy future for development in the Gambia.

The energy planning process also involves on-going re-evaluation of the supply-demand situation as it evolves. The enhanced position of fuelwood within the Gambia's overall energy supply system could serve two purposes, first to provide a secure baseline fuel as development proceeds, and second to allow a greater portion of scarce foreign exchange resources to be allocated to the variety of non-fuel commodities required for development.

CHAPTER 3

3.0 ENERGY BALANCE OF THE GAMBIA.

This chapter will discuss the energy balance of the Gambia, looking at energy consumption from an enduse perspective. End-use energy demand starts with the consumer, the person or organisation who is using energy, rather than the usual emphasis on supply. The enduse analysis begins by defining major energy consumption sectors. In general, these are households, industry, transport, agriculture and commerce.

3.1 INTRODUCTION.

As late as 1979 the belief was still widely held that of all the primary energy consumed in the Gambia, about 80% came from imported oil products, but, by 1982, the role of wood, charcoal and crop-wastes as fuels became generally recognized. The Gambia relies almost completely on imported petroleum to meet its commercial energy need, including the generation of electricity which is entirely diesel based. At present, the government is facing acute difficulties in servicing the petroleum import because of depressed export prices for the Gambia's major export, groundnuts, and low export prices for other agricultural produce. In practical terms, the country's options for reducing petroleum imports are limited by a relatively modest indigenous energy resource endowment. There is a possibility of oil and gas deposits in the Gambia's sedimentary basin but this requires systematic exploration and assessment of its cost effectiveness. Renewable energies like wind and solar are yet to make a full impact on the energy balance of the country.

The Gambia's energy policy as stated in the second Development Plan is aimed at using the scarce available resources, particularly fuelwood, more efficiently and reducing the import and consumption of petroleum products. It also plans to enlarge the energy resource base by the exploration for petroleum, increasing the fuelwood production and encouraging the use of alternative energy resources. The rapid depletion of the forestry resources call for drastic measures, the purpose of which will be to reduce the growth in fuelwood consumption. Fuelwood production can be increased by the exploitation of mangrove forests and the plantation of G'melina and the expansion of village woodlots.

The Gambian economy is based on non-energy intensive agriculture and groundnut production. The modern sector, which comprises tourism, commerce, public works, and small industries, is growing in importance due to the Gambia's role as a "gate-way" to the west African region.

The achievement of near and long term development objectives requires that energy resources of the proper type and magnitude be available to sustain the various sectors of the Gambian economy. As the population increases combined with a decrease in the foreign exchange earnings, depletion of indigenous wood fuel resources, and increasing constraints on high quality agricultural land availability, the need for appropriate policy intervention becomes increasingly urgent.

This chapter looks at the existing flow pattern of energy use in the Gambia from source through conversion process to the final point of consumption. Also highlighted is the need to secure adequate energy supplies to meet future needs and to minimize the cost of energy to the economy by improving the efficiency and conserving energy use in the Gambia.

3.2 END-USE ENERGY APPROACH.

The end-use approach looks at the demand side of the energy balance equation. It is based on the principle of disaggregation wherein energy requirements at the point of consumption are used as the analytic building blocks. Such an approach permits demand projections and provides a clear quantitative framework for evaluating the potential for and costs of alternative policy options by tracking impacts at the level of user equipment and behaviour adjustments. Further, the concrete relationship between economic goals, physical equipment stock and energy requirements can be specified. Finally, appropriate timeframes for effective phase-in of demand management policy options (e.g. fuel switching, efficiency improvement, pricing policy) and supply enhancement strategies can be evaluated.

The goal of disaggregation of demand at the point of end-use is limited by the availability and quality of data to characterize the type and quantity of the major categories of energy-using stock and their usage levels. The end-use demand also depends upon consumption patterns which may differ for social and economic reasons, e.g. between urban and rural households and at various income levels.

3.2.1 RESIDENTIAL SECTOR.

In 1991/92, end-uses associated with the residential sector consumed a total of 181,910 tonne of oil equivalent (T.O.E.) per year of energy, which is about 69% of the total final energy consumption in the Gambia. This is shown in table 3.1. Also shown in tables 3.2, 3.3 and 3.4 are figures for 1990/91, 1989/90 and 1988/89 representing 66%, 67% and 70% of the total final energy consumption respectively. Some of the data in these tables are illustrated graphically in figures 3.1 to 3.5. Fuelwood consumption within this sector accounts for 65% or more of the total national energy consumption. Thus, in designing a framework for fuelwood policy, the urban household sector warrants particular attention. Fuelwood consumption is expected to continue to rise although not as fast as previously due to the government's policy of encouraging households to use Liquid Petroleum Gas (LPG) instead of fuelwood. Some of the problems that need to be addressed regarding the introduction of LPG are as follows:-

(1) Cost - although more convenient to use it is lot more expensive than fuelwood.

(2) Fuel Security - sometimes there are shortages of LPG.

(3) Container Deposit - some householders find the deposit for the LPG container too expensive.

(4) Distribution - many householders have to travel a distance to purchase the LPG.

The urban householders that have become more thoroughly integrated into the commercial economy show marked qualitative changes in their patterns of energy usage. For instance, low to middle level urban households use kerosene for lighting. Middle and higher income households use LPG for cooking and sometimes for lighting. Finally, with rising income, electricity is used for an increasing variety of purposes. Electricity among lower and middle income users is utilized mainly for lighting, displacing kerosene within that end-use category. More affluent households expand and vary their uses of electricity. Electricity is used by such families for cooking, refrigeration, water heating and powering miscellaneous consumer durables.

Lighting accounts for about 15% of total electricity consumption in the developed world. Recent advances in lighting technology, especially in improvement of fluorescent lamps, could reduce projected energy consumption for lighting by 30-40% within a decade, with precedents for practice in the developing world [18].

The three strategies with the greatest potential are:-

(a) a change from filament lamps to compact fluorescent lamps;

(b) a change from mains-frequency fluorescent lighting to high frequency fluorescent lighting;

(c) the introduction of system of need-control of lighting, that is according to the need for light at a given place and time. This will usually be part of a Building Energy Management System (BEMS).

More efficient lighting technologies are of higher initial cost but the extra cost is usually recouped by the electricity savings within the lifetime of the first lamp. The reduction in lighting energy consumption depends on support from the government for energy efficient lighting. Policy options include:-

(a) Educating the population about the importance and benefits of conserving energy and its efficient use.

(b) Legislation to make the adoption of energy efficient lighting mandatory where appropriate.

(c) Provision of financing schemes including capital subsidies and leasing to overcome the first-cost barrier.

(d) Regulation of electricity companies requiring or encouraging them to promote energy efficient technologies.

Compact fluorescent lamps are about four to five times more energy efficient than filament lamps and last about eight times longer. This means that considerable savings can be achieved in both energy costs and maintenance costs, as illustrated in Table 3.5.

TABLE 3.1 - THE GAMBIA ENERGY BALANCE 1991/92 (In thousand of T.O.E.).

Primary Energy	Petrol	Diesel	Jet/Kero	LPG	Total Petroleum	Electricity	Fuelwood	Solar/PV	Total Energy
Production.							178.60	0.08	178.68
Imports.	24.15	42.02	20.19	0.54	86.90				86.90
Conversion									
Power Generation.		-7.21				7.21			
Losses (including power house).						-2.87			-2.87
NET SUPPLY	24.15	34.81	20.19	0.54	79.69	4.34	178.60	0.08	262.71
Final Consumption									
Residential.	0.24	0.35	0.20	0.54	1.33	1.96	178.60	0.02	181.89
Indust/Comms.	1.50	3.50	0.10		5.1	1.82			6.92
Transport.	17.32	23.65	15.65		56.62				56.62
Govt./Others.	5.09	7.31	4.24		16.64	0.56		0.06	17.26
TOTAL DEMAND	24.15	34.81	20.19	0.54	79.69	4.34	178.60	0.08	262.71

T.O.E.= Tonne of Oil Equivalent

Energy Equivalent	Unit	TOE	Energy Equivalent	Unit	TOE
Petrol	m^3	1.05	LPG	Ton	1.08
Diesel	m^3	1.02	Electricity	MWH	0.086
Jet/Kero	m^3	1.03	Firewood	$4.43m^3$	1.00

(Source:- Gambian Ministry of Trade, Industry & Employment. Energy Division).

TABLE 3.2 - THE GAMBIA ENERGY BALANCE 1990/91 (In thousand of T.O.E.).

Primary Energy	Petrol	Diesel	Jet/Kero	LPG	Total Petroleum	Electricity	Fuelwood	Solar/PV	Total Energy
Production.							172.80	0.08	172.88
Imports.	27.93	40.31	26.37	0.38	94.99				94.99
Conversion									
Power Generation.		-5.95				5.95			
Losses (including power house).						-2.07			-2.07
NET SUPPLY	**27.93**	**34.36**	**26.37**	**0.38**	**89.04**	**3.88**	**172.80**	**0.08**	**265.80**
Final Consumption									
Residential.	0.28	0.34	0.26	0.38	1.26	1.77	172.80	0.02	175.85
Indust/Comms.	1.40	3.30	0.20		4.90	1.82			6.72
Transport.	20.39	23.50	20.37		64.26				64.26
Govt./Others.	5.86	7.22	5.54		18.62	0.29		0.06	18.97
TOTAL DEMAND	**27.93**	**34.36**	**26.37**	**0.38**	**89.04**	**3.88**	**172.80**	**0.08**	**265.80**

T.O.E.= Tonne of Oil Equivalent

Energy Equivalent	Unit	TOE	Energy Equivalent	Unit	TOE
Petrol	m^3	1.05	LPG	Ton	1.08
Diesel	m^3	1.02	Electricity	MWH	0.086
Jet/Kero	m^3	1.03	Firewood	$4.43m^3$	1.00

(Source:- Gambian Ministry of Trade, Industry & Employment. Energy Division).

TABLE 3.3 - THE GAMBIA ENERGY BALANCE 1989/90 (In thousand of T.O.E.).

Primary Energy	Petrol	Diesel	Jet/Kero	LPG	Total Petroleum	Electricity	Fuelwood	Solar/PV	Total Energy
Production.							167.10	0.08	167.18
Imports.	21.95	41.00	22.87	0.19	86.01				86.01
Conversion									
Power Generation.		-5.12				5.12			
Losses (including power house).						-1.59			-1.59
NET SUPPLY	21.95	35.88	22.87	0.19	80.89	3.53	167.10	0.08	251.60
Final Consumption									
Residential.	0.22	0.36	0.23	0.19	1.00	1.64	167.10	0.02	169.74
Indust/Comms.	1.10	3.10	0.10		4.30	1.60			5.90
Transport.	16.02	24.89	17.74		58.65				58.65
Govt./Others.	4.61	7.53	4.80		16.94	0.29		0.06	17.31
TOTAL DEMAND	21.95	35.88	22.87	0.19	80.89	3.53	167.10	0.08	251.60

T.O.E.= Tonne of Oil Equivalent

Energy Equivalent	Unit	TOE	Energy Equivalent	Unit	TOE
Petrol	m^3	1.05	LPG	Ton	1.08
Diesel	m^3	1.02	Electricity	MWH	0.086
Jet/Kero	m^3	1.03	Firewood	$4.43m^3$	1.00

(Source:- Gambian Ministry of Trade, Industry & Employment. Energy Division).

TABLE 3.4 - THE GAMBIA ENERGY BALANCE 1988/89 (In thousand of T.O.E.).

Primary Energy	Petrol	Diesel	Jet/Kero	LPG	Total Petroleum	Electricity	Fuelwood	Solar/PV	Total Energy
Production.							161.60	0.05	161.65
Imports.	23.10	31.82	18.03	0.35	73.30				73.30
Conversion									
Power Generation.		-4.64				4.64			
Losses (including power house).						-1.42			-1.42
NET SUPPLY	**23.10**	**27.18**	**18.03**	**0.35**	**68.66**	**3.22**	**161.60**	**0.05**	**233.53**
Final Consumption									
Residential.	0.23	0.27	0.18	0.35	1.03	1.46	161.60	0.01	164.09
Indust/Comm.	1.50	2.90	0.09		4.49	1.49			5.98
Transport.	16.52	18.30	13.97		48.79				48.79
Govt./Others.	4.85	5.71	3.79		14.35	0.27		0.04	14.67
TOTAL DEMAND	**23.10**	**27.18**	**18.03**	**0.35**	**68.66**	**3.22**	**161.60**	**0.05**	**233.53**

T.O.E.= Tonne of Oil Equivalent

Energy Equivalent	Unit	TOE	Energy Equivalent	Unit	TOE
Petrol	m^3	1.05	LPG	Ton	1.08
Diesel	m^3	1.02	Electricity	MWH	0.086
Jet/Kero	m^3	1.03	Firewood	$4.43m^3$	1.00

(Source:- Gambian Ministry of Trade, Industry & Employment. Energy Division).

TABLE 3.5 - COMPARISON OF FILAMENT LAMP WITH COMPACT FLUORESCENT LAMPS FOR 8,000 HOURS LIFESPAN.

	Filament Lamp	Compact Fluorescent Lamps	
	GLS 100W	SL 25	PLCE 20
Lamp cost	£4 (8 x 50p)	£12	£14
Energy Consumed (in 8,000h)	800kWh (8x100Wx1,000h)	200kWh (1x25Wx8,000h)	160kWh (1x20Wx8,000h)
Electricity Cost	£80 (800kWx10p/kWh)	£20 (200kWhx10p/kWh)	£16 (160kWhx10p/kWh)
TOTAL COST	£84 (£4+£80)	£32 (£12+£20)	£30 (£14+£16)

The life of the filament and compact fluorescent lamps are 1,000 & 8,000 hours respectively. Their 1991/92 retail prices are given in table 3.5 and that of the compact fluorescent lamp is likely to fall. Cost and energy are compared over a period of 8,000 hours, corresponding to one year of continuous lighting or to four years with 2,000 hours lighting per year. The quantity of light produced is about the same in each ase. Electricity cost is 10 pence per kWh (1993/94 Gambian domestic tariff).

For the rural sector, it is observed that biomass constitutes the overwhelming basis for energy consumption. Electricity does not occur as a significant factor primarily because of limitations in the extent of the distribution grid. Fuelwood is used as the main energy source for cooking.

This sector is an area that can make better use of PV with efficient appliances, hence reducing the great demand for electricity on the utility company, Management Services Gambia Ltd. (MSG). The supplement of their energy needs could be met by the installation of some PV systems to power lights, refrigerators, electronic consumer items, etc.

3.2.2 AGRICULTURAL SECTOR.

It is an apparent irony that, while agriculture is the occupation of the working population, commercial energy consumption in the agricultural sector is extremely low (data unavailable). This is mainly due to the fact that agriculture in the Gambia predominantly relies on human and animal draught power and on direct passive solar power for the drying of crops. These energy sources are not accounted for in the energy balance.

3.2.3 INDUSTRIAL/COMMERCIAL SECTOR.

This sector accounts for about 2.6% of the total energy demand for 1991/92. Tourism is a major source of foreign exchange earnings in the Gambia, growing at an average annual rate of about 8% between 1982-92 [19]. While the absolute magnitude of tourism's contribution to energy use is not very large, it is an area that could make use of renewables hence reducing the total oil importation. There is potential for conservation and more efficient use of energy resources, e.g. through the use of active solar water heaters and low energy consumption appliances.

In the longer term, as new equipment replaces old, possibilities for improved energy use efficiency increases with the availability of technical experts.

Government conservation outreach programmes (or possibly financial incentives) could put energy efficiency planning higher on the agenda for industrial decision-makers.

In commercial and institutional buildings, the potential for cost-effective energy reductions appears substantial. End-uses of particular importance for policy targeting include air conditioning and ventilating systems in office buildings, hot water heaters in hotels, schools and hospitals. In particular, solar water heating instead of conventional fuel and electricity use would offer quick paybacks.

3.2.4 TRANSPORTATION.

Road transport accounts for over 80% of the world energy use by the transport sector as a whole [20]. In 1991, there were over 550 million vehicles in use around the world, of which over 400 million were cars. If historic rates of growth are maintained, the global vehicle population could exceed one billion within the next 20 to 40 years [21]. Motor vehicles are a major source of air pollution, probably larger than any other single man made source. They are responsible for much of the deterioration in urban air quality seen in cities around the world in recent years, and for photochemical smog, which can stretch over large areas in hot sunny weather. Road vehicles also make a significant contribution to acid rain and global warming [18]. This is why particular attention should be focussed on efficient vehicles, so that developing countries do not follow the same trend as the developed nations.

In 1991/92, this sector accounted for about 22% of the total energy demand in the Gambia. Consumption by the transportation sector is an important component of the commercial fuel requirements. This sector is almost entirely a user of liquid, petroleum based fuels.

A number of factors influence how much energy is used by vehicles including: engine size & efficiency, vehicle design, driver's skill, vehicle speed, level of maintenance, distance travelled and road conditions. Reducing energy demand in this sector as a whole will require a combination of measures including traffic restraint, promotion of public transport, walking and cycling, as well as an introduction of new vehicle technology. Increasing the efficiency of the vehicular fleet must be considered a priority in energy planning. With respect to private vehicles, there are two broad areas where efficiency increases could be effected:-

(1) improved performance standards for new and existing vehicles and

(2) improved patterns of traffic flow.

With regard to (1) above, consideration could be given to the adoption of minimum efficiency targets for new vehicles entering the Gambian fleet. High customs duty could be levied on low efficiency vehicles, to discourage their importation. Additionally, efficiency could be improved through programmes designed to upgrade the frequency and quality of vehicle maintenance.

With regard to (2) above, improvements in traffic flow could also improve fuel efficiency. Congestion in the morning and afternoon rush hours could be reduced by changes in the hours at which different offices report for duty. Some improvements in traffic flow could be implemented by the use of one-way streets in the Banjul and Serrekunda areas.

3.2.4.1 Petroleum Supplies.

The Government relies on private oil companies (like Shell and Elf) to furnish the country's petroleum supplies. Some difficulties have been experienced in maintaining this arrangement, mainly because of:-

(1) a breakdown of the West African Replenishment Programme (WARP) which was a pooling system for supplying petroleum to the region, and

(2) foreign exchange shortages which have undermined the ability of private oil companies to maintain their lines of credit to the Gambia.

3.2.5 GOVERNMENT SECTOR.

Fuel and electricity use within this sector could be improved by retrofitting existing equipment and designing cost-effective conservation measures into existing stock. In buildings with air-conditioners, there is a need for more insulation and in the efficiencies of lighting and other mechanical systems.

In few offices, the prospects for the retrofit of existing equipment are promising. Some offices have already achieved substantial energy savings through low cost upgrading such as increased insulation, thermostat control of refrigeration and more efficient use of motors.

The majority of organisations and firms are yet to investigate systematically or implement least-cost conservation strategies. They have not yet taken advantage even of the easier methods of reducing energy cost. There is an important role for the government to promote conservation through information and education campaigns, provision of assistance with energy audits and training of personnel.

3.3 ELECTRICITY GENERATION.

Electrical energy utilization requires two distinct conversion processes. At the end-use, electricity drives a variety of appliances (motors, pumps, heaters, lightbulbs, transformers, communication devices, etc.).

The secondary conversion stage involves the use of some primary energy source such as oil products to generate electricity. Energy losses occur at each of these two stages as well as in the transmission and distribution of electric power. From tables 3.1, 3.2, 3.3 and 3.4, it can be observed that the losses involved in the generation of electricity are as high as 40%, 35%, 31% and 31% respectively.

Electricity generated by the combustion of primary fuel is less efficient than the direct use of that fuel due to efficiency losses particularly at the secondary conversion stage where thermodynamic constraints limit practical conversion efficiencies to about one-third (electrical energy out to primary fuel in). However, electricity possesses some unique offsetting advantages. It is a high quality form of energy, which can be used as a source of both thermal and mechanical energy. The versatility of electricity as a "motive force" is a primary reason why historically it has been linked to industrializing and diversifying economies. The substantial advantages of electricity as an energy source suggest that the electrification of the Gambia should be a significant priority in the Gambia's medium term development strategy. Electricity is a major factor in the expansion of industrial activity [22].

Figure 3.1 THE GAMBIA ENERGY BALANCE 1991/92

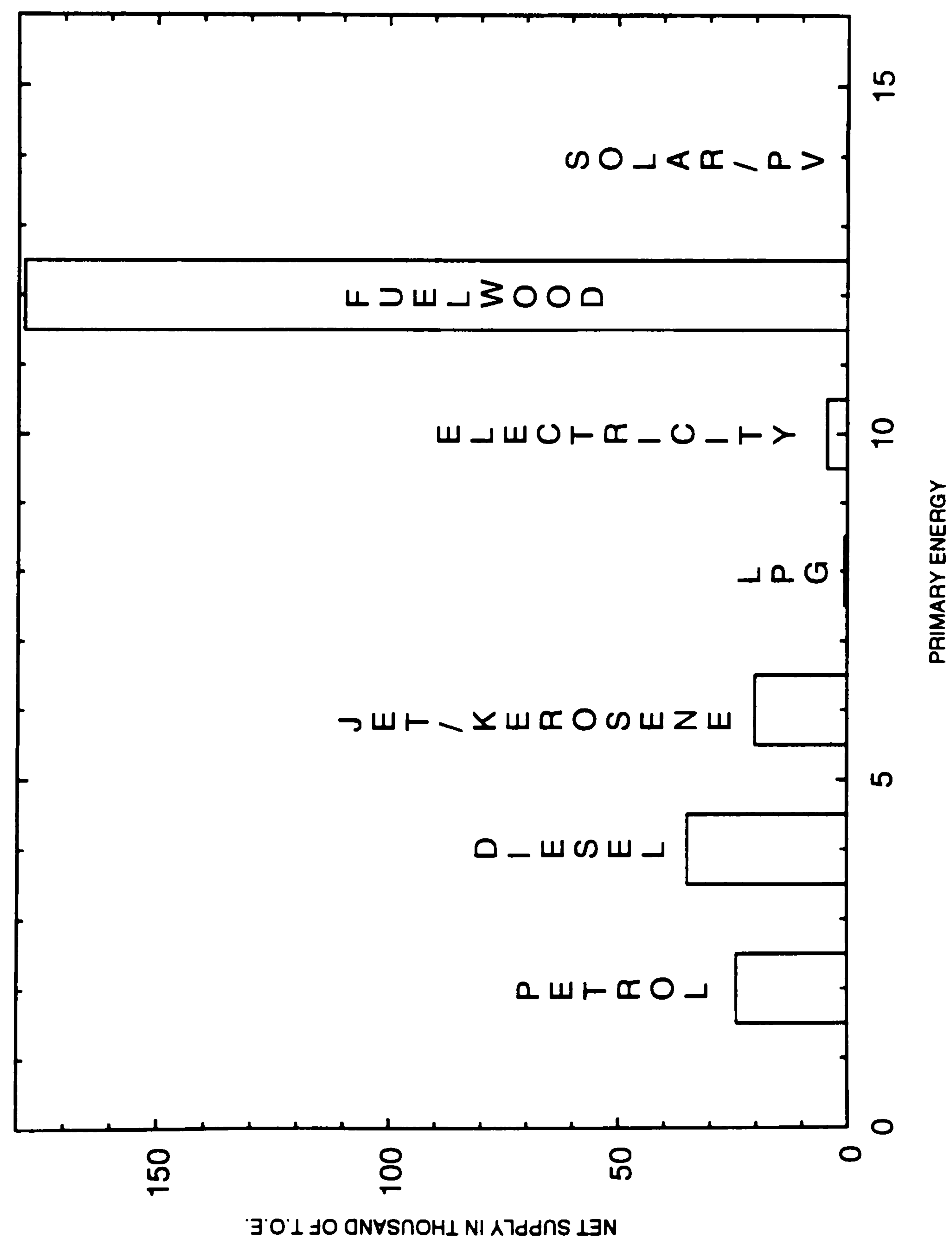
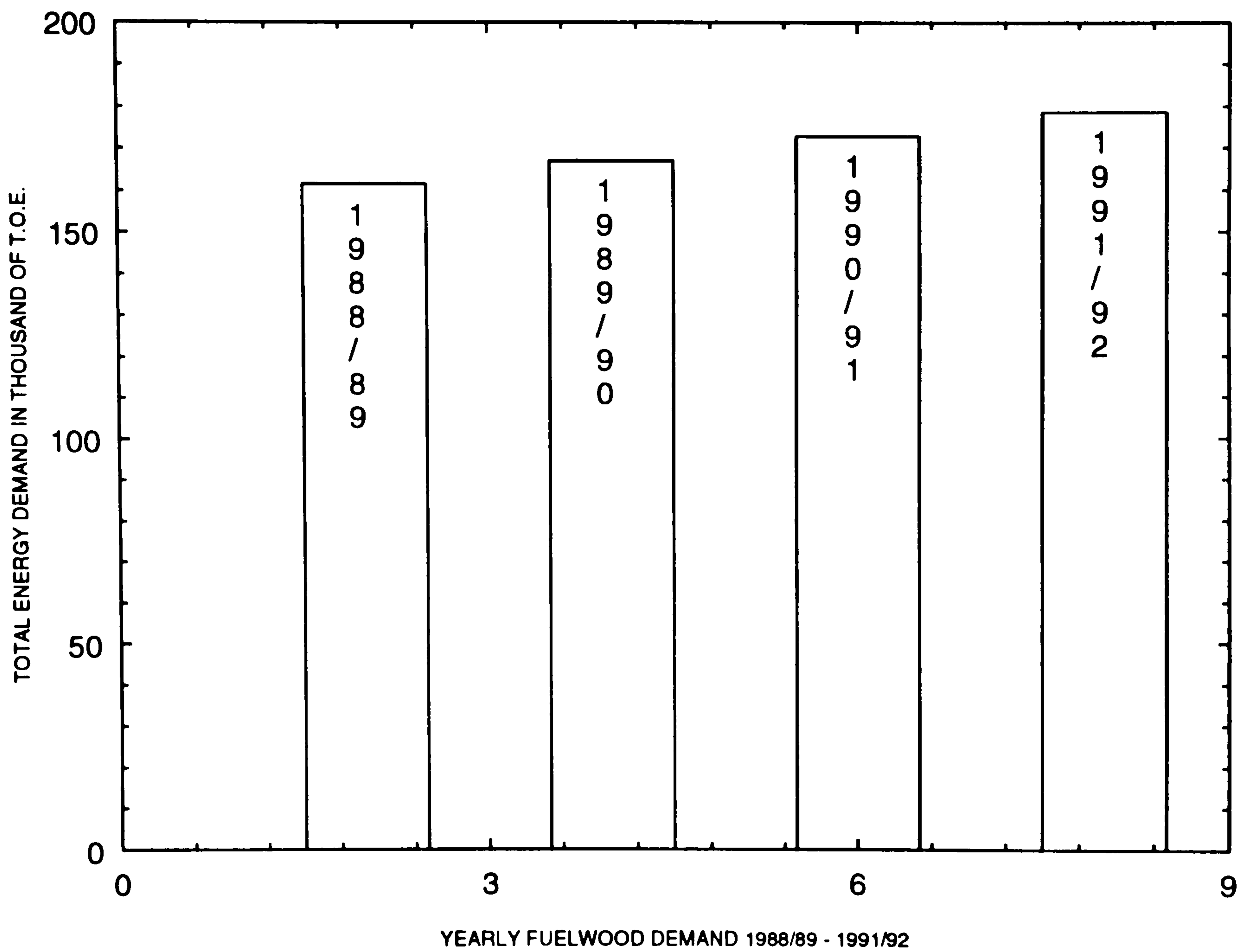


Figure 3.2 THE GAMBIA YEARLY FUELWOOD DEMAND 1988/89 TO 1991/92



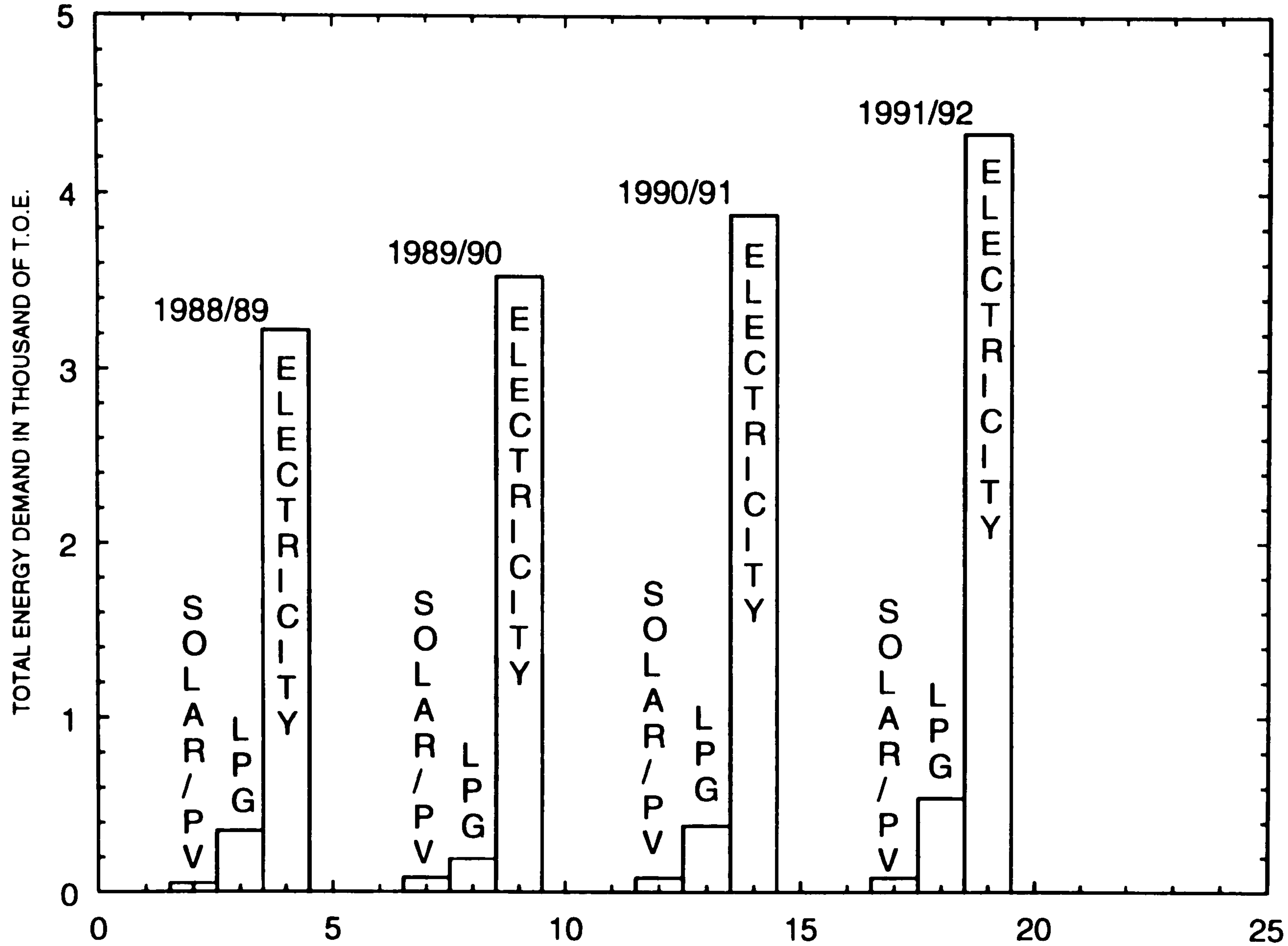


Figure 3.3 YEARLY ENERGY DEMAND 1988/89 - 1991/92

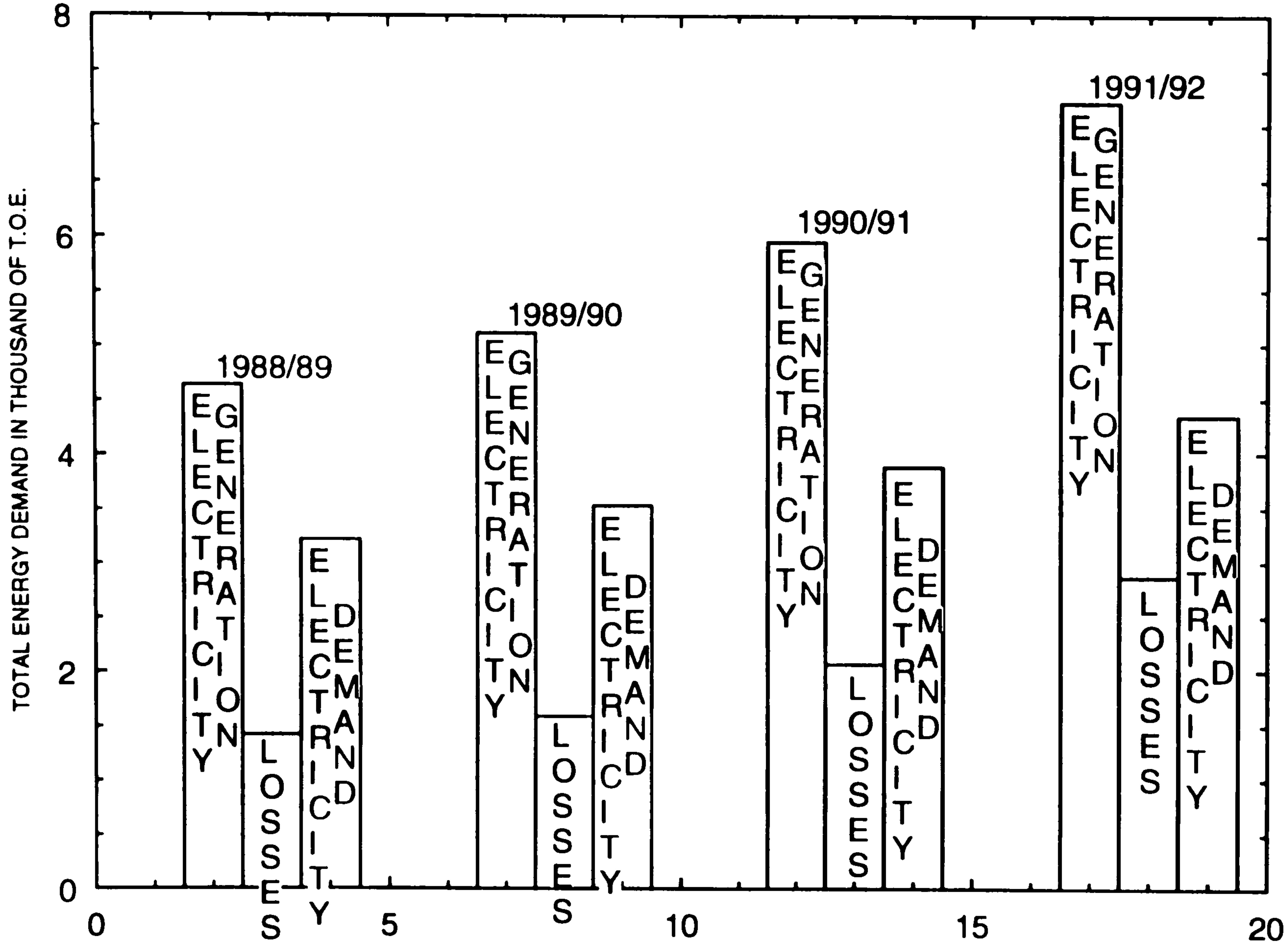
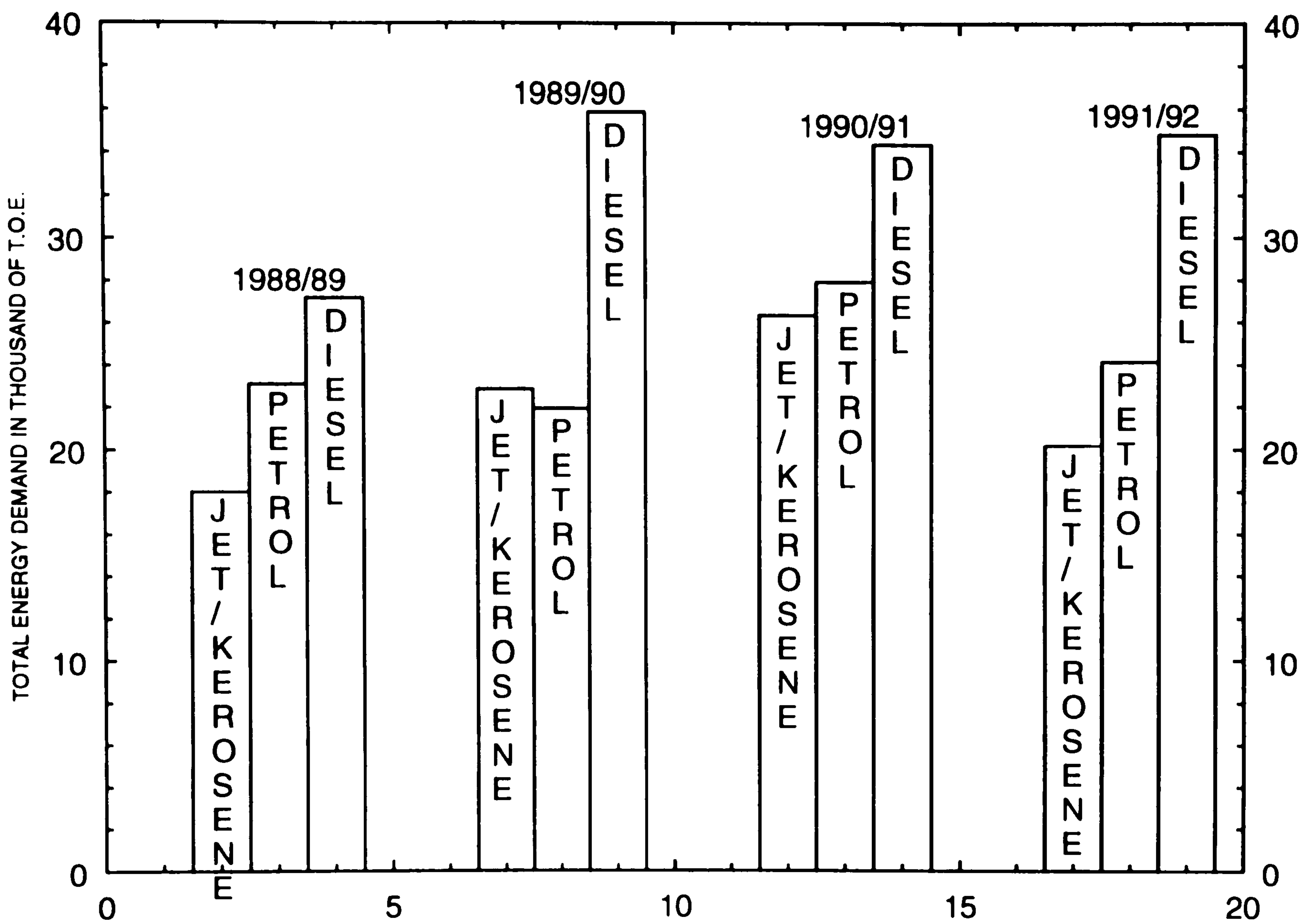


Figure 3.4 YEARLY ENERGY DEMAND 1988/89 - 1991/92



Fugure 3.5 YEARLY ENERGY DEMAND 1988/89 - 1991/92

3.4 DEVELOPMENT OF INDIGENOUS ENERGY RESOURCES.

Some of the possible energy resources in the Gambia are discussed below:

3.4.1 FUELWOOD.

The Gambia-German Forestry Project (GGFP) and the United States Aid for International Development Forestry Project (USAIDFP) were set up to manage the country's natural woodlands to sustain the production of fuelwood and other forest products. These projects are being carried out in conjunction with the Department of Forestry (DOF).

3.4.2 OIL AND GAS.

The Gambia is collaborating with Senegal and Guinea-Bissau in a joint study of the region's sedimentary basin. Progress is being made by Atlantic Resources Limited of Portugal, who have completed the first stage of retrieving, re-evaluating and re-processing available geological and geophysical data on the basin. The government is also being assisted by the PetroCanada International Assistance Corporation (PIAC) who has also completed a 600 km marine seismic survey in part of the basin.

3.4.3 HYDROPOWER.

There is very little hydropower potential in the Gambia because of the very flat nature of the country's landscape. The maximum elevation of the country is only 30 metres.

3.4.4 PEAT.

Recent discoveries of mangrove peat occurrences along sections of the Casamance river in Senegal have raised some interest in the possibility of similar occurrences along the Gambia river. However there is the likelihood that the fuel quality of any mangrove peat deposits found along the Gambia river will be as poor as that of the deposits in Western Senegal which were found to have a high ash and salt content.

3.4.5 COGENERATION.

Groundnut processing facilities are owned and operated by the Gambia Produce Marketing Board (GPMB). The GPMB has two processing facilities. One is at Denton Bridge which combines two decortication plants, two groundnut oil mills, a refinery and a small groundnut shell briquetting plant. The other is at Kaur with a decortication plant. The oil mill, refinery and one of the decortication plants at Denton Bridge are supplied with steam and electricity from an on-site power plant which is fired with groundnut shells.

3.4.6 FUELWOOD SUBSTITUTION.

Some of the surplus groundnut shells are used in briquetting plants to produce groundnut shell briquettes by an extrusion process and by a continuous carbonization plant to produce charcoal briquettes. The groundnut shell briquettes are intended to be used as a substitute for fuelwood and charcoal briquettes to be used as a fuel for ironing and cooking purposes.

3.4.7 SOLAR ENERGY.

The Gambia has significant solar energy resources as sunlight is available seven to ten hours per day for almost the entire year [23]. It has an average daily irradiance of 5.5kWh/m^2, making the use of PV very attractive. Solar energy is mainly used in the drying of crops and food preservation, although all life is dependent on solar energy. The conversion of this energy into electrical power (PV) is still yet to make a significant impact on the Gambia's energy balance. The Gambia's potential in generating huge amounts of energy from PV each day is indicated in table 3.6.

The solar radiation data of four stations in the Gambia compiled by the meteorological division of the Department of Water Resources are listed in table 3.6 as mean daily values for each month.

TABLE 3.6 - MEAN DAILY SOLAR RADIATION (kWh/m^2) FOR VARIOUS PLACES IN THE GAMBIA (10 year mean 1982-92).

Months	Yundum	Sapu	Kaiaf	Basse
January	6.19	4.26	5.52	4.65
February	6.86	4.75	5.81	4.83
March	7.17	6.12	5.74	6.62
April	7.29	5.69	5.76	6.29
May	7.03	6.10	5.86	6.41
June	6.34	5.56	5.40	5.84
July	5.67	5.44	5.19	5.64
August	5.61	5.41	5.33	5.34
September	6.15	5.29	5.41	5.59
October	6.27	5.51	5.38	5.79
November	6.15	4.46	6.42	4.56
December	5.87	4.09	5.69	3.97
Averages	6.38	5.22	5.63	5.46

3.4.8 WIND ENERGY.

Tables 3.7, 3.8 and 3.9 gives an indication of the daily mean wind speed of certain areas in the Gambia with a meteorological station. Most of these wind speed figures are too low to operate wind powered generators cost-effectively.

TABLE 3.7 - MEAN WIND SPEED AND DIRECTION AT YUNDUM (BANJUL INTERNATIONAL AIRPORT).

	1990		1991		1992	
Months	Speed (m/s)	Wind Dir.	Speed (m/s)	Wind Dir.	Speed (m/s)	Wind Dir.
January	4.12	NE	3.09	NE	3.09	N
February	3.09	N	4.12	NE	4.64	N
March	4.12	NE	4.64	N	4.64	N
April	4.12	N	4.64	N	4.64	N
May	4.12	N	4.64	N	4.64	N
June	4.12	W	3.61	W	4.12	W
July	3.61	W	3.09	W	3.09	W
August	2.58	W	2.58	W	3.09	NW
September	2.06	W	2.58	W	2.58	W
October	2.06	N	2.06	W	2.06	W
November	2.06	N	2.58	N	2.58	E
December	3.61	E	2.58	E	2.58	N
Monthly average.	3.31		3.35		3.48	

TABLE 3.8 - MEAN WIND SPEED AND DIRECTION AT BASSE.

	1990		1991		1992	
Months	Speed (m/s)	Wind Dir.	Speed (m/s)	Wind Dir.	Speed (m/s)	Wind Dir.
January	2.06	NE	1.03	N	1.03	E
February	1.55	NE	1.55	N	1.03	N
March	2.06	N	1.55	N	1.03	N
April	2.58	N	2.06	N	1.03	N
May	3.09	SW	2.06	N	2.06	W
June	3.61	SW	2.58	W	2.06	SW
July	2.58	SW	2.06	W	1.55	W
August	2.06	SW	1.55	W	1.55	SW
September	1.55	W	1.03	W	1.03	S
October	1.55	W	1.55	W	1.03	W
November	1.03	W	0.52	E	1.03	E
December	---		0.52	E	0.52	NE
Monthly average.	1.98		1.51		1.25	

TABLE 3.9 - MEAN WIND SPEEDS AT SAPU, GEORGETOWN AND KEREWAN.

Months	SAPU 1990 Speed (m/s)	SAPU 1991 Speed (m/s)	SAPU 1992 Speed (m/s)	GEORGETOWN 1990 Speed (m/s)	KEREWAN 1990 Speed (m/s)
January	2.88	2.11	1.44	4.17	4.27
February	2.21	3.04	1.85	4.17	3.91
March	2.16	1.49	2.83	3.45	3.40
April	2.16	1.50	1.85	3.04	3.71
May	2.37	1.55	2.11	3.50	4.22
June	2.99	1.60	1.29	4.84	4.43
July	2.37	1.24	2.37	4.43	4.79
August	2.01	1.18	1.85	3.30	4.38
September	1.96	0.93	1.70	3.66	4.02
October	1.70	0.98	1.03	2.94	3.71
November	1.39	0.93	1.91	3.55	3.81
December	2.99	1.85	0.98	3.91	4.12
Monthly average.	2.27	1.53	1.77	3.75	4.06

3.5 FUEL SWITCHING.

A reduction in the demand for fuelwood can be effected either through improvements in the end-use efficiency of rural cooking or through switching of fuels at the end-use. The latter could be achieved in principle, for example, by extending the central electricity grid, promoting decentralized technologies relying on indigenous sources of energy such as photovoltaics, solar heating, biogas, wind, etc., or by the introduction of "horizontal" technologies (e.g. maize milling) that would reduce the energy requirement for food preparation.

The conversion of wood to charcoal is 35-40% efficient in the modern masonry kilns and only 24% efficient in the earth kilns. These types of low energy conversion efficiencies needs serious consideration. There is a need to consider using more efficient wood stoves rather than charcoal and supplying the urban households which now burn charcoal with adequate fuelwood. These households should be persuaded to switch to more efficient wood stoves and hence the demand for wood resources would be much diminished.

Solar water heating could be used to displace an important fraction of the electricity consumed in hotels and residential homes for heating water. There is a sizeable unexploited potential for saving diesel oil and electricity by retrofitting existing water heating systems in the commercial/industrial sector. It is reckoned that a huge amount of fuel and electricity could be saved each year by installing solar water heating system at the fourteen major hotels and some of the bottling factories. Most of these potential users have expressed their interest in pursuing this option. A comprehensive technical programme to prepare detailed designs, tender documents for procurement and installation of equipment, and to supervise and monitor the initial operation of these systems is recommended to be undertaken by professionals in this field.

Another area of potential energy savings is the use of low-energy, efficient appliances. For example, some light bulbs like "compact fluorescents" uses only 20% of the energy of an incandescent bulb to produce the same light intensity [24].

Restrictions on installation of new electric water heating capacity could be an effective way of accelerating the transition which is already cost-effective in commercial construction.

3.6 CONSERVATION POLICY ISSUES.

In addition to the need for increased educational and training efforts on the conservation investment option, pricing and incentive policies may have an important role to play in the Gambia. Policies against energy subsidies should be introduced, so that prices would fully reflect the total cost of the energy used. This policy would increase the incentives of industries and companies to invest in energy-saving techniques. It might be argued that taxing energy would hurt industry, but the opportunities for conservation are so great that the effect on production costs could be kept to a minimum by good energy management.

There should be Government policy for an adoption of minimum efficiency standards for major appliances like motors, compressors and air-conditioning systems imported and sold in the Gambia. However, only such standards as would promise clear economic and energy benefits should be considered. New commercial building codes that encourage the use of passive solar cooling would also be beneficial.

3.7 END-USE ENERGY SERVICES.

Energy use in the Gambia has been on the increase and it is expected to continue increasing in the future. The increase in the services that energy provides is necessary and desirable, since energy services are essential for economic growth, improved living standards, and to provide for rising populations. For the Gambia, if alternative sources of energy are not identified for particular energy services, then much of the additional energy needed will be supplied by imported oil, thus further burdening the country which is already saddled with high oil import bills. The building of new power plants to meet higher demands for electricity could push this nation even deeper into debt.

Energy efficient and renewable technologies offer the means of largely avoiding a trade-off between energy use, economic growth and environmental quality. Energy efficient technologies, in particular, can reduce life-cycle operating and capital costs of providing energy services, while largely sidestepping the environmental damages associated with conventional energy supply strategies. As awareness of these opportunities grows, so will the market for these technologies.

3.7.1 RESIDENTIAL SECTOR.

Between two and three times as much commercial energy is used in domestic activities as in agriculture, mainly for cooking, ironing and food processing [25]. Food processing and preservation is an important area for further development in ensuring adequate nutrients all the year round.

Quite a lot of valuable foodstuffs are wasted each year because of inadequate energy for preservation. Adequate and continuous energy supply is needed for refrigeration systems to store perishable food.

Energy for lighting is needed for increasing the length of the productive day. Some farmers who are busy in their farms during the day can supplement their income by doing some arts and craft work and textile work during the evening. These products could be sold at the tourist markets around the country and some exported to earn foreign currency.

3.7.2 AGRICULTURAL SECTOR.

The majority of the energy needs in the agricultural sector comes from human and animal labour. Relatively small quantities of energy from commercial sources are used for irrigation and water pumping. Even smaller amounts of energy go into the production of fertilizer for farmers.

Although at the present moment, it is important to continue to develop the draught animal system, it is also vital to look ahead into an industrialised and mechanised agricultural system. This will demand greater supply of energy, proper infra-structure and organisational set-up.

It need not however demand greater use of fossil fuels. Crop drying could be done by the use of solar dryers and water pumping, lighting and small motive power by PV, providing much improved energy services with little increase in fossil fuel use.

3.7.3 INDUSTRIAL/COMMERCIAL SECTOR.

The energy demand for this sector is low. Energy demand will rise as the Gambia continues to develop its industries to meet the demand from the tourist industry and the domestic needs. Most of the consumer items used in the hotels are imported. A large portion of these imported items could be manufactured in the Gambia with some of these items exported to neighbouring countries.

It would be very difficult to raise rural average incomes to a satisfactory level unless employment can be increased in the countryside. This could be in the form of agricultural modernization, where agriculture-related industries in villages and small cities of rural regions are provided with additional energy beyond the needs of agriculture and domestic use.

With the electrification of villages, villagers will be given the opportunity to install and operate small power looms for production of textile goods, which could be shipped to the cities for final processing. Water pumps and small engines could be manufactured in small machine shops with the aim of expanding into larger machine tool shops.

For development of rural industries which can be competitive with some of the more centralized industries of large cities, an essential requirement is relatively low-cost energy to operate lathes, looms and other machinery, and to provide energy for metal-working, dairies and food processing.

Renewable energy sources, particularly solar heating and PV could provide a significant amount of the energy needs of such small industries.

3.7.4 TRANSPORTATION.

Improved transportation is needed to bring off-farm inputs to the farm, e.g. fertilizers, pesticides, high-yielding seed varieties, farm tools, farm machinery and to facilitate exporting part of the crops to cities and towns. It is obvious that farmers will not be able to purchase the off-farm inputs necessary for modern agriculture unless they are able to sell a portion of their crops to non-farmers. In general, modernization of agriculture demands improved transportation both to lower the cost of getting inputs onto the farm and the costs of transportation of farm products to people in the cities and towns.

To minimise the increase in demand for imported fuel, it is essential to have a much more efficient transportation system and perhaps to consider the possibilities of bio-diesel production in the Gambia.

3.8 CONCLUSION.

The end-use energy approach assesses the demand side of the Gambia's energy balance equation. Such an approach permits demand projections and provides a clear quantitative framework for evaluating the potential for and costs of alternative policy options by tracking impacts at the level of user equipment and behaviour adjustments.

The residential sector warrants particular attention in the amount of fuelwood consumption. There is an urgent need for this sector to reduce its fuelwood consumption by switching to alternate source of energy. The groundnut shell briquettes could be used as a substitute for fuelwood and charcoal to be used as a fuel for ironing and cooking with more efficient stoves. Failure to act now could seriously damage the Gambian forest. The energy needs for lighting within this sector could be reduced by up to 40% by using energy efficient appliances.

The energy consumption in the industrial/commercial sector is currently low. Industry is growing, especially in the area of tourism. There is a need for strategies to encourage this sector to use renewables like PV and solar water heaters where it is feasible.

One of the major causes of pollution is from the transportation sector. Particular attention should be focussed on efficient and less polluting vehicles.

In the government sector there is still room for energy conservation and improved efficiency. These measures could be found to be cost-effective within a short period.

The losses involved in the generation and distribution of electricity are quite high. Although the losses have reduced slightly during the last few years, there is still scope for more improvement.

This analysis has considered the needs for energy services in the various sectors of the Gambian economy. It has established that there are numerous areas where renewable energy sources could supply the needs of those sectors, giving enhanced security and reduced import bills.

CHAPTER 4.

4.0 ROLE OF RENEWABLE SOURCES OF ENERGY.

Chapter four describes the function of some renewable energy sources. Some of these renewables are appropriate sources of energy for development.

4.1 INTRODUCTION.

As part of the change in energy policies which followed the "oil crises", many industrialized countries expanded their development efforts in Renewable Sources of Energy (RSE), and substantial technical progress was made. A small fraction of these efforts has been devoted to applications in developing countries. A major problem, therefore is to screen, select, adapt and manage emerging energy technologies for the developing countries. Governments and non-governmental organisations have a crucial role to play in this area. They may assist the build-up of a local energy research and development (R&D) and manufacturing capability in developing countries, which is the long-term but necessary basis for a balanced energy development.

There is a strong interaction between RSE and commercial energy, such as oil. The current slackening of the oil market will certainly make oil more affordable to some and thus make many renewable energy projects less attractive.

The flexibility required to achieve progress with RSE requires that attention be paid to questions of both supply and demand. Fuel and technologies will have to be matched to the task, which also means that RSE and conventional energy must be seen as complementary to each other. The need for such a complementary strategy is now increasingly being recognized by governments of developing nations. Current energy plans for The Gambia categorically state that neither conventional nor renewable energy can solve the problems of rural and urban energy development on their own. For the foreseeable future, it will not be possible to supply the rural areas with oil or grid power in large enough quantities to support the desired economic growth. This means an increased reliance on local energy sources and therefore RSE. Also, in the longer run, RSE can be seen as a promising and, indeed, necessary complement in the national energy mix.

4.2 FUELWOOD: FORESTRY AND AGROFORESTRY.

Fuelwood is the major energy source mainly for cooking, for most people in The Gambia and many developing countries [26]. It accounts for over 65% of the total national energy consumption in the Gambia's energy balance during the last six years. This situation is likely to remain so for the foreseeable future. However, serious deficits are now appearing in many places and show sign of worsening and becoming much more widespread. A way of stopping this deteriorating situation is by intensive tree-planting on a very large scale [27]. On-going developments in forestry for energy include tree-planting methods. Local participation is essential, in order to achieve economic and social viability in fuelwood supply in rural areas. Urban and industrial demand can, however, often be met competitively by large-scale plantations. One of the main problems in tree-planting is to find the right species, methods and organisational approach for different social circumstances. The impact on the national energy balance is often crucial, and in local terms it is sometimes a question of survival [28].

Fuelwood is often seen as the fuel of poor rural dwellers in developing countries. Increasingly, however, these fuels are the urban fuels preferred even in high income households in developing countries because supplies can be guaranteed and it is the cheapest available fuel. Additionally, fuelwood is increasingly used in the commercial and industrial sector [29].

In many developing countries, wood is frequently the cheapest available fuel not only per unit weight but also per unit of heat. No special facilities are required for wood storage and, in addition, it is safe to store the energy supplies for long periods. When dried, fuelwood burns safely.

Careful planning must be done if conventional forestry is to provide part of the future fuel requirements. Particular attention has to be paid, within the wood monoculture systems, to obtaining a sustained off-take from the forest throughout the crop cycle. Above all, the low priority which is accorded to conventional fuel production, a low priority that is mirrored by the lack of investment, should be reversed.

A potential area of investment is where the private sector is given demarcated forest areas to manage. They will be responsible for supplying industry with their wood needs and also for replenishing the forest with cultivated tree-seedlings. This form of wood-forest management will ensure sustainable wood supplies to both industries and householders. This will enhance the future development of the carpentry and wood-craft business for the tourist industry and for export.

4.2.1 FIREWOOD AND CHARCOAL.

The estimated firewood consumption in developing countries is about 1.5 billion m^3, which was some 83% of total timber use in these areas, and about 90% of all firewood used in the world. The amount has increased by 26% over ten years, which keeps pace with the 25% growth in population during the same period. The total growth of the world's tropical forests is between 10 and 20 billion m^3 per year [30]. In theory this is more than enough production capacity, but, in reality, the supply is extremely uneven, and in vast areas firewood shortages are growing alarmingly. This is because forest areas are rarely used for energy. Trees outside the forest are the principal source of fuelwood, although charcoal is often made from larger scale clear-cutting, particularly close to urban markets.

Figures on the magnitudes and trends of fuelwood supply and demand are of such an alarming character that most international agencies have given urgent priority to the problems. For example, in a recent study of 15 developing countries, Food and Agricultural Organisation (FAO) found that the present rate of fuelwood plantation establishment would have to be increased by more than 10 times to 70,000 hectares per year to avoid predicted shortages at the turn of the century [30][31].

4.2.1.1 <u>Reducing consumption.</u>

Most firewood today is burned in simple, three stone fireplaces with limited efficiency. The large scale introduction of improved stoves is therefore one possibility to reduce consumption.

4.2.1.2 <u>Making better use of available wood.</u>

Whilst areas around the urban centres regularly face shortages, remote forest areas may have vast potential in the form of logging residues and other waste. One bottle-neck is usually transportation, whilst another is management and marketing. Charcoal production brings down haulage costs considerably and urban dwellers are often accustomed to this handy fuel. The inefficient kilns being used make cooking with charcoal much more wood-demanding than using fuelwood directly.

Fuelwood, in addition to water and shelter, is a basic need for the vast majority of people in developing countries. It is unrealistic to believe that a long-term, large-scale solution to the fuelwood crisis can be achieved among subsistence and semi-subsistence rural people if it is not predominantly based on a strategy of individual land users catering for their own needs.

The integration of trees and other woody perennials into farming systems, using species, management techniques and spatial/temporal arrangements which are ecologically and culturally compatible with local practices, holds a great potential. A well conceived agroforestry intervention could achieve an increased production of such wood and at the same time address many of the problems related to land productivity and sustainability.

4.3 ENERGY CROPS.

Generally most plants could be used for energy purposes. Some are already being cultivated specifically for producing energy, due to their high photosynthetic efficiencies, or ease of conversion to useful fuels. There also exist many other plants which potentially could provide large amounts of energy [32]. The most promising energy crops are trees, already discussed in section 4.2. The contribution of energy crops (apart from wood) to the Gambia's energy balance is unaccounted for mainly because of inadequate means to measure its impact and the amount involved could be very low. This is an area with tremendous energy potential that the Gambia could exploit for future sources of energy.

This section will look at some energy crops, such as herbaceous and hydrocarbon crops as well as aquacultures.

4.3.1 HERBACEOUS CROPS.

A number of tropical grasses have high growth rates and could be grown and harvested for energy purposes. In the Gambia, elephant grass (Imperata cylindrica) and papyrus are fast growing grass varieties with harvestable yield as high as 32 ton/ha/yr. The grass is air-dried then compressed into fuel pellets. It is a relatively clean and convenient fuel.

These pellets could be used by a householder as fuel for cooking and heating water. Small industries like goldsmiths, silversmiths and blacksmiths could also use it for fuelling their furnaces. This would reduce the need for charcoal and fuelwood to do the same job.

4.3.2 HYDROCARBON PLANTS.

Some plant species have the characteristics that can yield hydrocarbons or hydrocarbon-like substances upon extraction. These can be potential fuels or feedstocks for the chemical industry, depending on their molecular weights. Generally, lower molecular weights are more suitable for fuel purposes [33]. At present hydrocarbon plantations are only at experimental stages, and it is too early to judge their potential for success and economic viability.

The natural rubber tree in Brazil (hevea brasiliensis), for example, produces a latex consisting of very high molecular weight hydrocarbons (not usable as fuel). Others, such as the 'genus euphorbia' and particularly 'euphorbia lathyrus' seem promising for the production of hydrocarbon fuels. Extraction yields liquids resembling petroleum with an oil content of about 1.5 ton/ha/yr.

There are a number of algae which can also produce hydrocarbons. Botryoccus braunii, for example, has been shown to yield 70% of its extract as a hydrocarbon liquid, closely resembling crude oil.

In the future there could be a break-through in the research with these hydrocarbon plants, hence enabling the Gambia to grow its own for local use with a possibility to export if the market exists.

4.3.3 AQUACULTURES.

There is a tremendous potential for increased production of seaweeds and other aquatic cultures to fuel biogas plants for the production of energy, at small, intermediate or industrialized levels [34]. One of the most promising aquatic plants for developing countries is the water hyacinth (eichornia crassipes). This is a rapidly growing fresh water weed, and is notorious for its ability to clog up lakes and waterways. It is especially fast growing on nutrient rich, polluted waters. It has high protein, mineral and vitamin content, which makes it suitable as food, animal fodder and fertilizer to recycle into the aquaculture system to keep up nutrient levels. Because of its high moisture content it can be easily digested in biogas plants to yield a methane rich gas plus a residue which retains all the mineral nutrient contents of the original harvested weed, and which can consequently still be used as fodder or fertilizer.

The growing of energy crops can, in some circumstances, supplement existing energy supplies. The production of herbaceous and hydrocarbon crops specifically for energy purposes is still in the experimental stage. It is not known how the price of fuels derived from these processes will compare with other energy sources. In both cases the selection of the species is of great importance and requires site-specific decisions. Given their bulk, these crops will either have to be used for on-site combustion, or converted to a higher fuel.

In some cultures aquatic plants have traditionally been farmed for food, so their production requirements are known. What is new is their conversion to energy; however, enough experiments have been done to show their economic and ecological viability. There is a great future energy potential in these plants.

4.4 AGRICULTURAL RESIDUES & ORGANIC WASTES.

As fuelwood has become more scarce in many parts of the developing world, an increasing number of people have been forced to turn to straw, crop stalks, animal dung and other agricultural residues as an alternative cooking and heating fuel [35]. Increasing numbers of Gambians in the rural areas are depending on agricultural residues as their energy source. The term 'agricultural residues' is used here to describe the full spectrum of biomass materials that are produced as byproducts from agriculture. It includes woody residues, crop straws, crop processing residues, green crop residues and dung. The use of agricultural by-products in both the rural and urban areas of the Gambia will help to reduce slightly the dependence on imported fossil fuel.

4.4.1 WOODY RESIDUES.

These are crops like corn cobs, millet stalks, jute sticks, coconut shells, pigeon pea, cotton stalks, etc. They burn well and are often a popular fuel for cooking.

4.4.2 CROP STRAW.

These are crops like rice, wheat, etc. The straws from these crops are made into bundles, bales, or briquettes to become more convenient fuel. It could then be used as a fuel source in a steam-powered electricity generator.

4.4.3 CROP PROCESSING RESIDUE.

These are residues like peanut shells, coconut husks, rice husks, coffee husks, etc. These are generated in large quantities at crop processing factories. In the Gambia, peanut shell briquettes are used in homes as a substitute for charcoal and powering steam engines for electricity production in some industries.

The economy of briquetting is very site specific. It depends on the cost of collecting the residues, the scale of production and transportation requirements to the end users. A typical example of the cost involved with the Gambia briquettes project, funded by the United Nations Sahelian Office (UNSO) and the Danish International Development Agency (DANIDA), is given in table 4.1.

The plant capacity is 5.52 ton/hr. The annual production period is 5.5 months. The raw material is groundnut (or peanut) shells which have no other value. The work is carried out by three shifts of 8 hours/day for two months on an alternate basis. The effective hours of operation are 1,360 and the total production is 7,510 tons of briquettes (160,000 bags of 47 kg. each).

TABLE 4.1 - ANNUAL COST OF THE GAMBIA BRIQUETTES PROJECT [36].

		(Years depreciation)	US$/year	US$/ton
Plant	399,000	10	39,900	5.31
Planthouse	69,825	10	6,983	0.93
Storage	83,125	20	4,156	0.55
Maintenance of plant & generator			25,365	3.38
Labour			28,215	3.76
Energy (diesel)			28,262	3.76
Bags (for distribution)			15,152	2.02
Transport			71,345	9.50
Administration (10% of total cost of $219,378)			21,938	2.92
			------	-----
			241,316	32.13
Wholesale price				32.13
Transport				1.82
Retailers cost and profit margin				9.80

Grand Total Per Ton				$43.75

The price of fuelwood in the urban areas varies between 57 and 62 US dollars per ton as compared to US$43.75 for groundnut briquettes. It is worth pointing out that the cost of groundnut briquettes on an energy basis (i.e. per energy value) is cheaper than the cost of commercial fuelwood with a similar calorific value of 952 kJ/kg. It is also about one third of the corresponding cost for oil fuels. This cost comparison is carried out for the urban areas in the Gambia [36].

4.4.3.1 Briquette Technology Dissemination.

The dissemination of the use of briquettes is dependent on a whole series of circumstances:-

(a) There has to be knowledge that such a technology exists.

(b) There has to be an adequate raw material that does not have competing end-uses.

(c) There has to be a way to obtain the right equipment.

(d) There has to be knowledge of how to run and maintain it.

(e) There has to be an accepted market and end-use for the briquettes.

Some of the problems experienced with the groundnut briquette project are:-

(a) Some of the people do not want to use the briquettes for cooking purposes because they give off too much smoke. However work is going on in reducing the amount of smoke emitted.

(b) The transportation cost involved in distributing the briquettes to many small end-users is high.

(c) There are some technical problems with the running of the briquetting equipment.

4.4.4 ANIMAL DUNG.

Dried cow, buffalo and horse dung makes a relatively good cooking fuel. Its main problem is that it tends to produce a lot of smoke, that it can be irritating to the eyes and lungs. Dung makes an excellent fertilizer and the removal of the dung from the fields to be used as a fuel will have a direct impact on the soil. Biogas digesters can be an answer to this dilemma as these produce both energy and fertilizer from dung.

In most farming systems, the amount of agricultural residues produced each year is extremely large. With most cereal crops, for example, for every ton of grain at least a ton and a half is produced. A healthy cow or buffalo produces as much as five times its own weight in dung each year. Though rarely measured, dung and crop residues are in fact a major resource, often comprising the largest single element in biomass production at the village level.

There is a great potential in using waste and residues for energy production. The main limitations of increased reliance on these include: competing demands, existing energy uses, seasonal supply, etc. Particularly large potential exists in the fuelling of certain agricultural and food-processing activities, which themselves produce these wastes.

The economic viability of using wastes and residues for energy purposes depends very much on the specific waste and the purpose for which it will be used. In many situations the wastes and the residues either have to be disposed of at great cost or are simply dumped, resulting in pollution. In the case of alcohol production from cassava, for example, the final alcohol cost per litre is halved if the various wastes and effluents are also utilized in the production process.

4.5 PEAT.

In developing countries, where sizeable peat deposits exist, peat could contribute not only to the substitution of oil, but also to domestic fuel supplies. Peat can be regarded as the lowest grade of coal. It is a heterogeneous mixture of partially decomposed organic matter (plant material) and inorganic minerals that have accumulated in a water-saturated environment. Such an environment inhibits active biological decomposition of the plant material and promotes the retention of carbon which would normally be released as gaseous products of the biological activity. Consequently, there is an accumulation of organic material which is known as peat. It is formed in swamps, bogs and salt waters, some of which are still under water whilst others are now on dry land. The rate of peat formation is very slow. Peat could be a promising energy source when large and suitable quantities are available [37][38][39].

There is a possibility of finding peat in the Gambia but it is feared that any discoveries might reveal a low quality of peat.

4.6 BIOFUELS.

The material of plants and animals is called biomass. It is organic carbon based material that reacts with oxygen in combustion and natural metabolic processes to release heat. The initial material may be transformed by chemical and biological process to produce intermediate biofuels such as methane gas, ethanol liquid or charcoal solid. The initial energy of the biomass-oxygen system is captured from solar radiation in photosynthesis.

As the standard of living in the developing world improves so the demand for energy increases. Mechanical energy in the form of shaft power will be needed for the development of industry, agriculture and transportation systems. In fact, improvement of standard of living is possible through increased productivity, requiring increased industrialization and modernization of the agriculture and transportation sectors. This will inevitably lead to an increased need for shaft power.

In developing countries, where electric energy is often not available where power is needed, internal combustion engines using a petroleum fuel are frequently used in stationary applications.

Petroleum imports in the Gambia's energy balance accounts for well over 30% of all energy consumed in the country during 1988 to 1992. The increasing cost of petroleum fuels and the growing awareness in non-oil producing countries, like the Gambia, of the potential risks associated with a very large dependence on imported petroleum fuels have led to a rapidly increasing interest in alternatives to the petroleum fuelled internal combustion engine for shaft power production.

4.6.1 BIOGAS.

Biogas is produced from the conversion of organic material and it is used for direct combustion in cooking or lighting, or indirectly to fuel combustion engines delivering electrical or motive power.

The biogas production process involves the biological fermentation of organic materials such as agricultural wastes, manures and industrial effluents in an anaerobic (oxygen-deficient) environment to produce methane (CH_4), carbon dioxide (CO_2) and traces of hydrogen sulphide (H_2S). In addition to the gases produced, the fermentation of these materials reduces them to a slurry containing a high concentration of nutrients making them especially effective and valuable as fertilizers. A further by-product of the process is its positive effect on public health. Bacteria harnessed in reducing the organic material to slurry and biogas kill pathogens (disease-producing bacteria) usually found at high concentrations in manures and which pose a severe threat to human well-being [40].

4.6.2 ALCOHOL FUELS.

Ethanol (C_2H_5OH) and methanol (CH_3OH) are well-established as commercial engine fuels. Ethanol is a volatile liquid fuel that may be used in place of refined petroleum. It can be an additive or direct substitute for modified engines [41]. It is manufactured by the action of micro-organisms and is therefore a fermentation process. Conventional fermentation has sugars as feedstock. Methanol, a toxic liquid, is made from the catalytic reaction of H_2 and CO at 330^oC and at 150 atmosphere pressure.

4.6.3 VEGETABLE OILS.

Some of the crops that can be used for the production of vegetable oil are:- coconut, cotton seed, groundnut, palm kernel, rapeseed, soy bean, sunflower, sesame and linseed.

There are two alternative extraction technologies in use, namely mechanical pressing and solvent extraction. Mechanical pressing is the simpler way to extract the oil. Screw-presses are most common in modern practice. In such units the feedstock is normally pre-heated and then fed into the press which consists of a warm shaft rotating within a barrel. As the material passes through the press, the pressure increases and the oil is extracted continuously.

The most effective method for vegetable oil production is solvent extraction in which a chemical solvent such as hexane is used to extract the oil. This will leave only about 1% of the oil in the residue. Solvent extraction requires relatively large units and sophisticated technology and thus is not too well suited for local application in developing countries.

Vegetable oil could be used for edible purposes or as fuel for lighting or engines. It is possible to bring its properties closer to those of gasoil and at the same time bring about a significant reduction of the viscosity to approximately the same order as for gasoil or methyl ester. Blending gasoil with vegetable oil is another method of making vegetable oil fuel more similar to gasoil.

4.7 DRAUGHT ANIMAL POWER.

Animals have been used for centuries throughout both the developed and developing worlds to either replace or supplement the need for human energy expended in transportation and the production of food. There are approximately 400 million draught animals in the developing world. They are valued at US$ 100 billion, would cost US$ 250 billion to replace by petroleum based fuels and provide the people of developing countries with over 150 million horse power [30][42]. During their working lives such animals, in addition to providing this level of motive power also contribute fuel for rural communities, and fertilizer for the soil. When their useful working life ends, animals are still useful in that they provide food and a number of other valuable products such as hide.

Draught animal power can only fulfil its true potential if conscious attempts are made to upgrade it. Upgrading draught animal power systems does not necessarily mean that more animals have to be brought into use, although this is required in a number of countries, including the Gambia. Only a well equipped infra-structure can upgrade draught animal power and emphasis should be placed on raising output from the same system by:-

(a) Increasing the amount of time for which draught animals are utilized.

(b) Improved feeding and health care system.

(c) Improved implements and carts.

(d) Better recovery and use of by-products during the working life.

(e) Improved genetic and breeding programmes.

Draught animal power should not be seen as a backward technology in conflict with mechanization and modernization. On the contrary, it is considered that it will be the only feasible and appropriate form of energy for large groups of people in many countries for years to come. The bulk of animal work is carried out in rural areas, so most technological improvements will directly affect the efficiency of agricultural practices. It is being increasingly recognized that the core of the energy strategy for increasing farm productivity in the developing countries depends mainly on the appropriate combination of human, animal and mechanical power for specific situations within the country, including the technical suitability and economic and social objectives [43][44]. The energy contribution of draught animals to the Gambia's energy balance is omitted because of the nonexistence of official statistics. It is believed to play a vital role in the agricultural and transportation sector. One of the many useful roles is in animal-powered pump technology, enabling the availability of water during the dry season.

4.7.1 ANIMAL-POWERED PUMP TECHNOLOGY.

Animal-powered water pumping efficiencies are being increased by improved system components and designs. Some of the animal-powered water-raising system are described below:-

4.7.1.1 The Sack & Rope Water-Lifting

This system is mainly used in the Sahel region and it utilizes the motive power of a camel or bull to lift individual sacks of water from a well. About 2,000 litres of water per hour can be lifted from wells 6 metres deep, and often this method is used to lift water from far greater depths.

4.7.1.2 The Sakia

With this system water is collected from wells up to 1.5 metres deep. It consists of a vertical galvanized steel wheel with clay pots mounted on the wheel's periphery. The wheel is driven by a single animal or pairs of animals walking in a circle around the well. Power is transferred to the pump by means of a cast-iron right angle gear drive. This is shown in figure 4.1.

As the steel sheet wheel rotates, water collected at the periphery gravitates to the centre of the wheel where it is discharged at ground level. With an efficiency of about 60%, the sakia system can supply about 30 litres of water per second from wells up to 1.5 metres deep with a single ox providing the motive power. Typical operation involves two oxen, each working a total of five hours to lift water for 10 hours per day. The system is estimated to cost about US$34 per hectare of land requiring irrigation.

4.7.1.3 The Chain & Washer Pump

This system as illustrated in figure 4.2, operates on the principle of a continuous looped chain and washer being pulled through a closely fitting pipe, over a geared wheel and back to the foot of the pipe to pass once more up the pipe with its next load of water. With the inclusion of a cast iron right angle drive, the system can be adapted for animal power. The maximum practical lift is 15-20 metres and, when driven by a pair of bullocks, about 14 litres of water per second can be supplied from a 4 metre well, dropping to 9 litres per second from a 6 metre well. This system is estimated to cost about US$44 per hectare of land requiring irrigation.

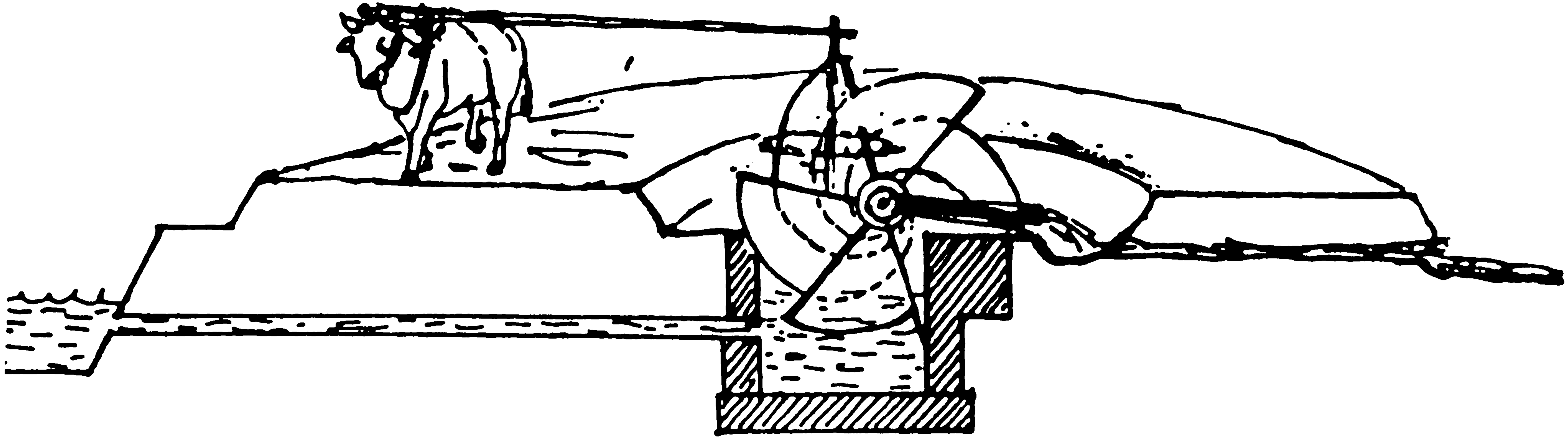


Figure 4.1 The sakia pump [30]

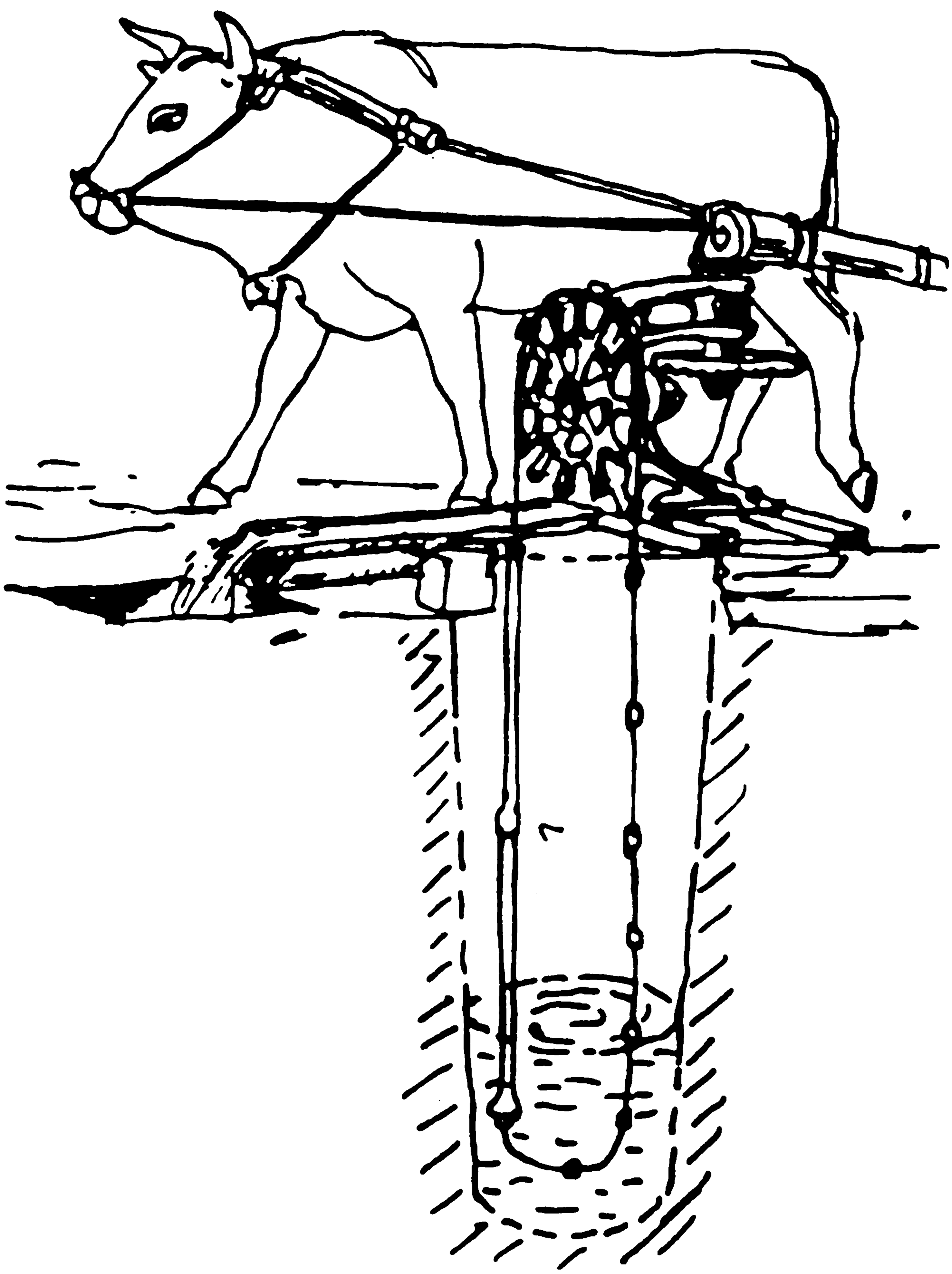


Figure 4.2 The chain and washer pump [30]

4.7.1.4 The Mono Pump

This system incorporates a gearbox and a rotating pump. The mono pump was developed in the UK and uses a positive displacement, helical rotor/stator pump and a gearbox, as shown in figure 4.3. With this system, the turning speed is directly proportional to the water flow, but the output pressure of the raised water remains virtually independent of the speed. The system can be used in wells up to 110 metres and delivers 1,200-4,600 litres of water per hour depending on the availability of animal power. Another system, made by the Bunger company in Denmark, is claimed to have a production capacity of 8,000-10,000 litres of water per hour from wells 7-8 metres deep. The pump costs about US$2,400.

Animal-powered pumps may have a great potential in some areas, but they are not always the most economic solution. Economic analysis has shown that, for irrigation, animal-powered pumps could sometimes be the best option for small farms of 1 to 5 hectares.

Dissemination of the pumping systems has been slow despite the cost advantages for small farms, mainly because of ignorance of the merits of the proposed systems and a shortage of funds to pay for installation.

If such systems are to become widely used, like the traditional pumps, they must be simple, durable, reliable, cheap, easy to maintain and should contain components made in local workshops using locally-available materials. Imported materials and components add significantly to the system costs.

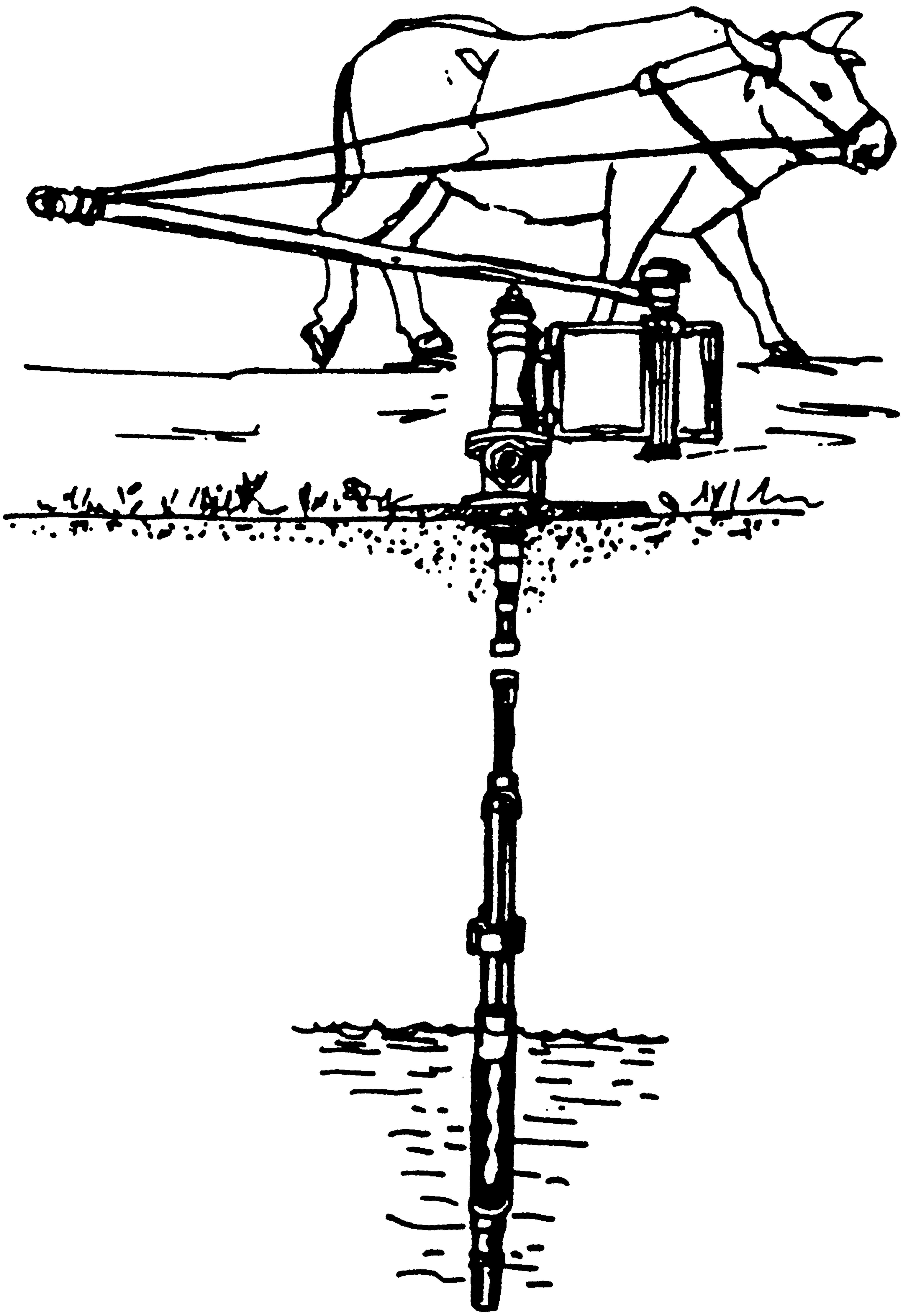


Figure 4.3 The mono pump [30]

4.7.2 INFRA-STRUCTURAL NEEDS FOR DRAUGHT ANIMAL-POWER.

(1) There is a need for a scientific feeding and breeding programme in order that the animals will be able to carry out assigned tasks.

(2) Comprehensive veterinary health services are essential. Funds and facilities are needed to control and eradicate animal diseases. Research work is being carried out by the International Trypanotolerance Centre (ITC) in the Gambia in the fight against trypanosomiasis caused by tsetse fly and other related diseases.

(3) There is a need to strengthen the existing "extension aid working scheme". In this scheme trained extension workers in all aspects of animal power make farmers aware of the benefits of better draught animal-power systems. Educational training and demonstrations are given at the village/farm level.

4.7.3 ECONOMIC ASPECTS.

The benefits of using animal rather than human labour were illustrated in field trials in Sierra Leone [45]. It was found that maize cultivation by hand, including hoeing, seeding and weeding took 160 man days/ha/year whereas this was reduced to only 50 man days with the use of an ox. Groundnut cultivation which took an average of 182 man days/ha/year by hand was reduced to 30 days when using an ox, hand-cultivation of cow peas taking 240 man days/ha/year was reduced to 112 days, and swamp rice cultivation by hand took 197 man days/ha/year as opposed to 82 man days with the use of an ox. In addition it was shown that, with the use of animal power, a farmer could plan to plant and harvest more accurately and carry out these activities at the most appropriate times, thus producing up to 20% increase in yield and better product quality, adding significantly to his/her crop value. The study also revealed that the farmer now had the ability to intensify cultivation, use multi-crops, grow inter-season crops and cultivate green fertilizer.

The use of draught animal power does have significant impact on the increased production and improved quality of agricultural products. It also benefits the transportation sector of most developing countries, especially in rural areas. In certain cases, animal power has been found to be more economical than mechanized agricultural equipment and motorized transport.

4.8 HYDROPOWER.

Hydropower is mainly used for the generation of shaft power from falling water. The power is then used for direct mechanical purposes or more frequently, for generating electricity [46]. Unfortunately, there is very little hydropower potential in the Gambia because of the flat nature of the country's landscape.

4.9 OCEAN POWER.

The level of water in the ocean, sea or river rises and falls according to predictable patterns. The change in height between successive high and low tide and the movement of the water produces tidal currents, which may reach high speeds (~5m/s) in coastal and inter-island channels.

4.9.1 TIDAL ENERGY.

This is site specific, requiring mean tidal differences of greater than 4m and also favourable topographical conditions, such as estuaries or certain types of bays, in order to be economically viable. Its viability is limited in the very near future for the Gambia.

4.9.2 WAVE ENERGY.

The energy carried by ocean waves is large; typical mean values are between 20-70kW/m of wave front. A shoreline of 1km would thus receive 20-70MW which, converted to electric power with an efficiency of 50%, would produce 10-35MW. Wave energy resources are, however, unevenly distributed.

Several recent optimistic estimates regarding the cost of electricity from wave power fall in the range of US cents 3-6 per kWh. These have proved encouraging enough to merit further R & D programmes; however, other estimates are less optimistic. Several years of R & D may lie ahead before viable, competitive wave power plants become available [47].

4.10 WIND POWER.

The first electricity-generating wind machine was developed in Denmark in 1890. Soon afterwards engineers realized that, to generate electricity efficiently, fewer and thinner blades were needed compared with the blades used in the traditional windmills and windpumps. These new machines found a wide market in Denmark, the United States and a few other countries during the twenties and thirties. Many were used for water pumping and some for electricity generation to farms and other remote operations without access to a central grid. Wind power made a vital contribution to the development of the great plains of the USA and the remote areas of Australia.

There are also several regions where wind electricity may well come to play an important role in developing countries both in supplying electricity in remote areas and supplementing conventional generating plant in the main grid [48][49]. Development of modern wind energy equipment is, however, both difficult and expensive and should be avoided by developing countries. Such countries are advised to consider using the technologies developed by the developed nations.

It may seem more beneficial to develop an indigenous wind-powered system in developing countries rather than importing systems produced in distant countries. Such a belief may be acceptable with many of the renewable energy technologies but, in the case of wind, this is not always the best path to follow. The development of modern wind energy systems is an expensive and skilled process and is, therefore, not, in general, appropriate to most developing countries which often do not possess the necessary financial or technical resources for research in this field. Although some developing countries are capable of having the technology licensed to them for local production, this will involve some form of technology transfer, detailed discussion of which is given in chapter seven.

If it can be accepted that reliable, proven technologies in this field already exist and are in commercial production, it is then necessary to consider where and how such systems can make an impact on the development of under-developed areas. To begin with, any country considering using wind electricity technologies must first evaluate its own wind regime to discover whether there is a sufficient wind energy resource to warrant the installation of wind turbine generators. Generally, two bladed wind generators of 200kW have been noted to be cost-effective at an average windspeed of 6m/s or greater, although the cost-effectiveness depends on the type of wind generator and the windspeed pattern of the region installed. At the present moment, wind power generators do not look quite favourable in the Gambia with a maximum monthly average of 4.06m/s in Kerewan. It could become cost-effective in the future, with novel generator designs operating at much lower wind speeds. Some of these details and further specifications are usually given by the manufacturer.

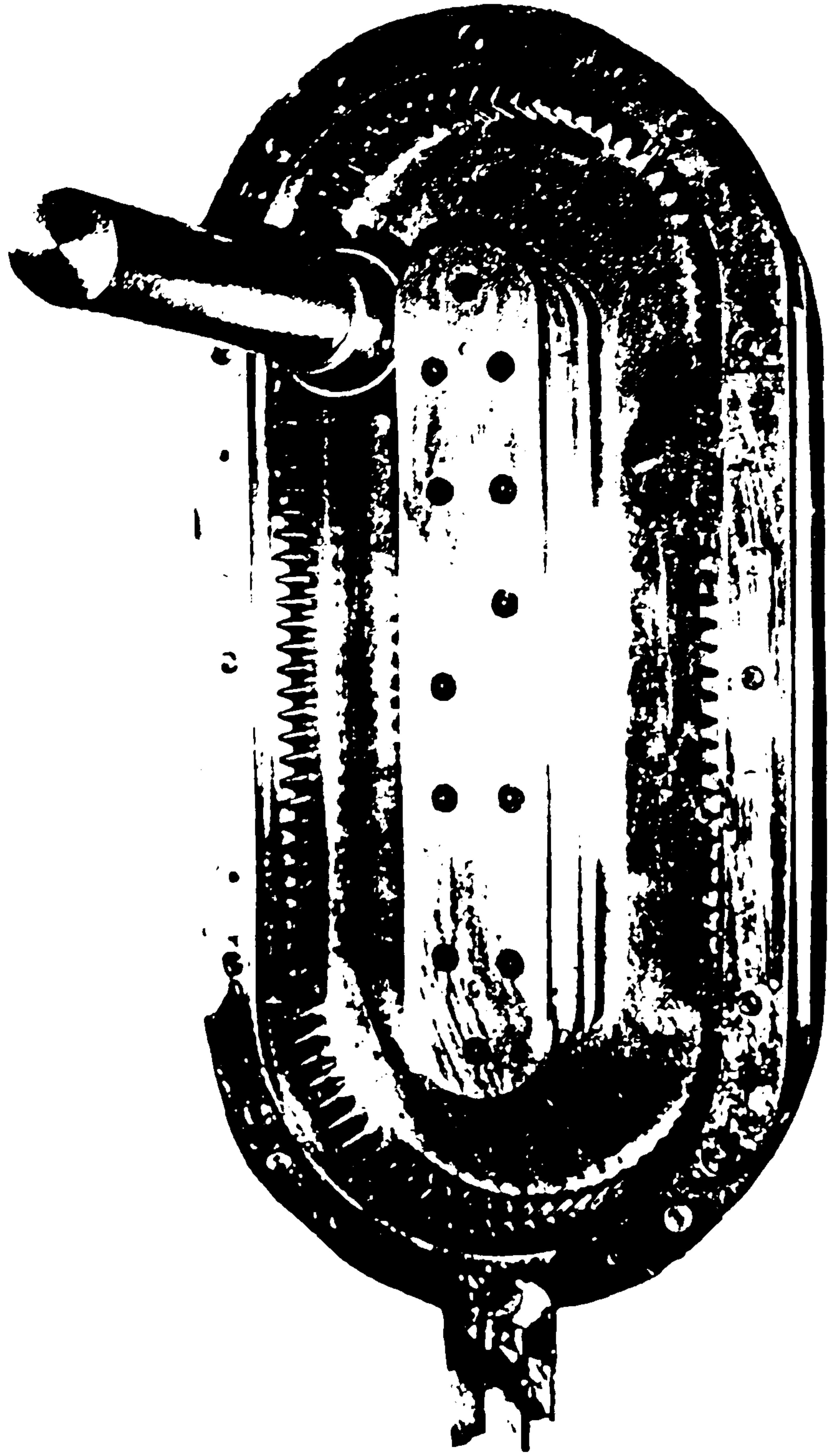
Successful wind turbine designs are the result of many years of development and field testing. Consequently the best wind turbines are those which have been in operation for some time and potential wind turbine users are advised to avoid machines that have not been fully field-tested for at least two years.

4.10.1 WINDPUMP.

The new IT Power windpump, shown in figure 4.4 with its gearbox, has been installed and pumping water at its test site at Silsoe, Bedfordshire. This windpump is of novel design with future prospects, especially in areas of the Gambia with average wind speed of less than 4m/s. The system can operate under very low wind speeds, as low as 3m/s. For areas where wind speeds are low for long periods of time this can significantly improve the overall volume of water pumped.

This windpump has a three metre diameter rotor and stands on a ten metre tower at the test site on Silsoe Campus, part of the Cranfield University. The innovations include a novel gearbox and pitch control of the rotor blades for storm protection. The gearbox mechanism is unique amongst most commercial windpumps in avoiding the use of a crank to drive the pump. A crank requires a compromise between being as long as possible to give a long pump stroke but as short as possible to allow easy starting. This new windpump gearbox avoids this

Gearbox



Multi-Bladed Rotor

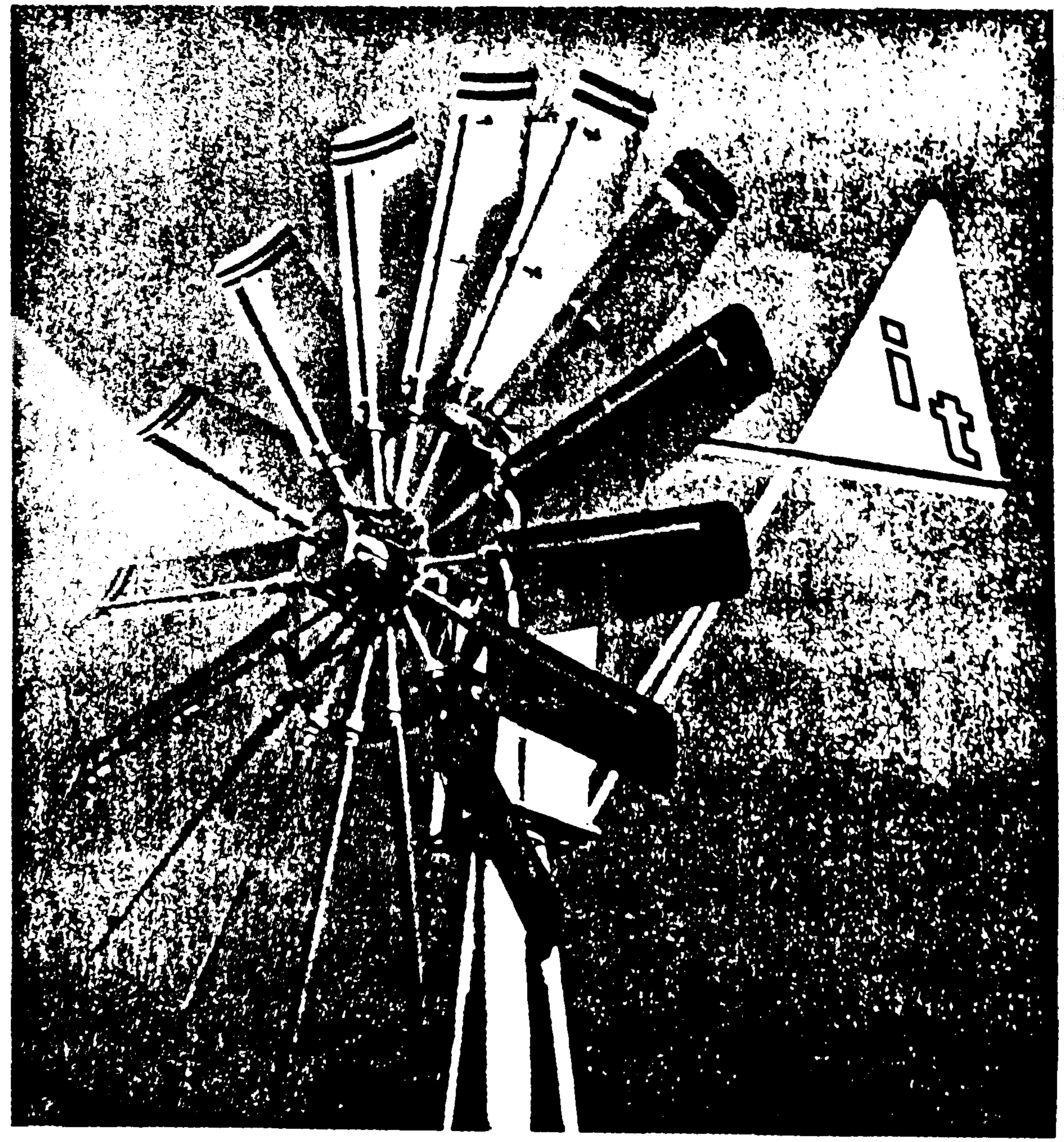


Figure 4.4 The IT Power Windpump [50]

compromise. It is an oval epicyclic gearbox with fixed pinion in which, contrary to a crank mechanism, the length of stroke is totally independent of the effective crank length. It is aimed to develop this prototype for low-cost manufacture in developing countries whilst maintaining reliability.

4.10.2 ECONOMIC CONSIDERATIONS FOR WINDPOWER GENERATION.

Wind generator power costs are heavily linked to the characteristics of a wind resource in a specific location. The cost of supplied power declines as wind speed increases, and the power supplied increases in proportion to the cube of the wind speed.

Matching available energy and load requirements is also important in wind energy economics. The correct size of wind generator must be chosen together with some kind of storage or co-generation with an engine or a grid to obtain the best economy. The ideal operation is a task that can utilize a variable power supply, e.g. ice-making or water purification.

Regarding the economics, the choice of interest rate obviously has a major effect on the overall energy cost. With low interest rates, capital intensive power sources such as solar and wind are favoured. Other factors bearing a strong influence on the economics of wind electricity are the standard of maintenance and service facilities and the cost of alternative energy supplies in the particular area.

4.11 SOLAR ENERGY.

A concept to which all of us have been exposed at some time in our lives is the image of our sun as an enormous heat source, the "furnace" of our solar system. In fact, apart from comparatively small contributions from gravitational and nuclear interactions, every process that has ever occurred on this planet was fuelled, directly or indirectly, by energy from our sun. With this in mind, it can be seen that the sun is the "prime mover" in this neighbourhood of the universe. Although solar energy is abundant and inexhaustible, it is highly variable, intermittent and thinly distributed over a wide area.

4.11.1 PASSIVE SOLAR HEATING AND COOLING.

When an object absorbs sunlight it gets hot. This heat energy is usable in various ways for heating or cooling. The solar heating or cooling of housing or working spaces can be accomplished without any machines or moving parts, but simply by the appropriate design of the buildings. Such architectural designs were incorporated into buildings well before the advent of Christ. The advent of cheap and abundant fossil fuels led to the abandonment of these traditions, but they are now being re-established on a firm scientific basis, and termed as passive solar technologies. These technologies will help reduce the Gambia's dependence on fossil fuels for heating water and air-conditioners for cooling buildings.

4.11.1.1 Solar Water Heating.

The most common conception of the use to which solar energy can be put centres on the heating of water in solar collectors. This is the most common solar technology in use around the world. Shown in figure 4.5 is a solar water heating system, and when the fluid in the solar collector is hotter than the water in the pre-heat tank, the circulating pump is switched on. The hot fluid from the collector is sent through the heat exchanger to heat the water in the pre-heat tank, from where it is either used directly or stored in the hot water tank.

The common type of solar water heater in the Gambia incorporates a $2m^2$ flat-plate solar collector and a 200 litre storage tank. The price of this heater is about US$ 300. In 10 years, which is assumed to be the life time of the solar water heater, a corresponding electric heating system would consume about US$ 1,095 worth of electricity. In developing countries, although the energy currently used for water heating is in the order of 5-8% of total domestic energy consumed, the availability of reliable solar water heaters at affordable costs could reduce pressure on commercial energy, i.e. electricity produced from oil [51][52].

Work is in progress to develop new, low cost materials and combinations of materials capable of withstanding conditions usually associated with developing countries such as high heat and humidity, and

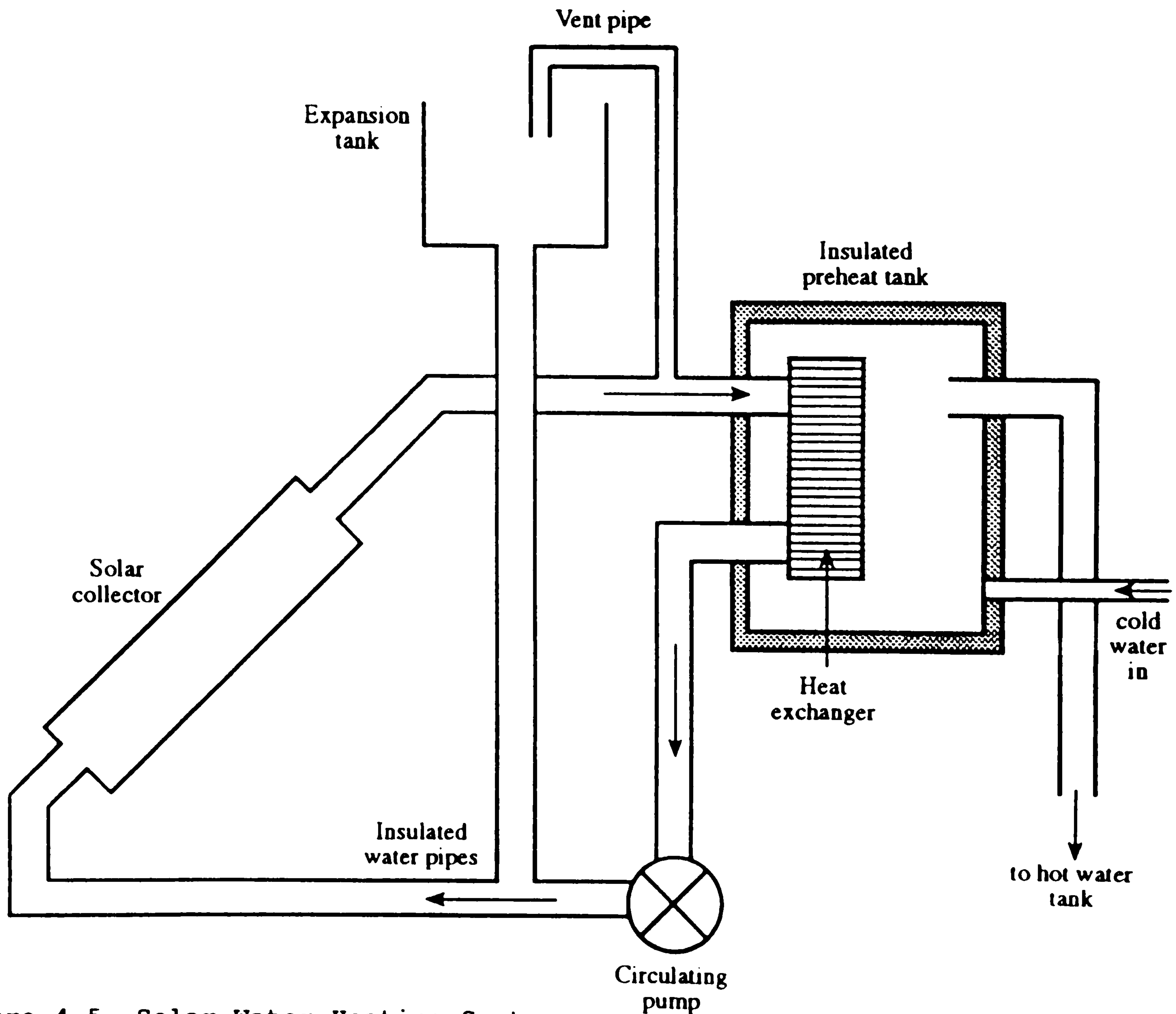


Figure 4.5 Solar Water Heating System.

water of high sediment and corrosive element content. Lightweight reinforced concrete is being tried in the construction of both collector and storage tanks, as is plastic and, in some cases, rubber. Although these materials offer cost advantages over steel and copper (currently the commonest material in use), the need to employ sophisticated and expensive machinery in the complex fabrication of systems using these materials detracts from their attractiveness in the developing world. In addition, repairs to plastic and rubber require special tools and techniques often unavailable in developing countries.

4.11.1.2 Passive Cooling of Buildings.

Buildings can be designed so that the heat of the sun induces convection currents which draw cool air into the building and so reduce the inside temperature. Islamic architecture has used this principle for centuries and many of its buildings have a "chimney" which draws up hot air and brings air into the building past north facing surfaces which remain cool throughout the day. Instead of being circulated in the building, the hot air is vented to the atmosphere while the incoming air is cooled by underground, or north facing, heavy masonry surfaces.

In the Gambia, radiative cooling could be incorporated into buildings by using "No heat" aluminium sheet roofing. This special type of aluminium sheet (from Granges Aluminium in Sweden) reflects most of its heat into the atmosphere and not into the building. During humid periods of the year, dessicant cooling could be useful. Moisture absorbing materials such as salt, coconut husk or charcoal are used. The absorbing material has to be replaced at regular intervals to maintain the cooling effect. The growing and watering of trees, plants and grasses will also assist in the cooling of nearby buildings.

4.11.2 SOLAR DRIERS.

Most crops require special treatment after harvest, to prevent rapid decomposition and the growth of fungi. Drying of crops after harvesting is an especially important process in the preservation of agricultural produce. At present most crops produced in the rural areas of the Gambia are dried using the open-air, sun-drying method.

Developing countries suffer heavy losses of food in the post-harvest period. This resulting high level of crop wastage is of critical importance in the economies of countries largely dependent on agricultural produce, and such large food losses further aggravate economic development problems already being experienced by most developing countries [53].

Open-air drying is appropriate for some cases but brings major disadvantages in others. For example, product quality can only be optimized when drying temperatures are controlled. Also the produce cannot easily be protected from the elements and scavenging animals, especially when it needs to be spread over large areas in order to dry.

In order to dry a material adequately, it is first necessary to know the initial moisture content of the material to be dried and the desired moisture content of the final product. Drying rates are controlled by the rate at which heat is applied to the product, the rate at which the product's internal moisture is released from its surface and the rate at which moist air is removed from the area surrounding the product. The drying rate is controlled by varying the heated air temperature and humidity and, since insolation levels can vary widely, solar driers must be carefully designed if steady drying conditions are to be achieved.

The wide variety of solar driers developed over the years can be generally divided into:-

4.11.2.1 Natural open-air driers.

These are of a very simple construction. The material to be dried is placed outdoors on a tray, a rack or the floor, and is dried by ambient sunshine and wind. Some of these driers can have a fixed or movable roof to protect the crop against rain.

4.11.2.2 Direct solar driers.

In these driers the material to be dried is placed in a transparent enclosure of glass or plastic. The sun heats the material to be dried and the enclosure causes a heat build up due to the "green house effect". Sometimes ventilation through the enclosure is introduced via vents or chimneys.

4.11.2.3 Indirect solar driers.

In these driers the sun does not act directly on the material to be dried, thus making them useful in the preparation of those crops whose vitamin content can be severely diminished by the action of sunlight (e.g. vitamin A in carrots).

4.11.3 SOLAR COOKER/OVEN.

In this system solar energy is harnessed to cook food. Solar cooking devices fall into two main categories; (i) solar ovens and (ii) direct focussing solar concentrators. Well over 95% of all fuelwood consumption in the residential sector is for cooking. Solar cookers could make a significant contribution to the Gambia's energy needs by saving part of the wood resources. This can only happen if they gain widespread social acceptance, since many householders might be reluctant to change their way of cooking. A sketch of a solar oven is shown in figure 4.6. The oven consists of a massive, cubic heat storage covered on three sides and the top with a layer of Transparent Insulation Material (TIM) and weather protected by a glass pane. The large thermal mass of the oven allows storage of solar energy and cooking times need not coincide with maximum solar input.

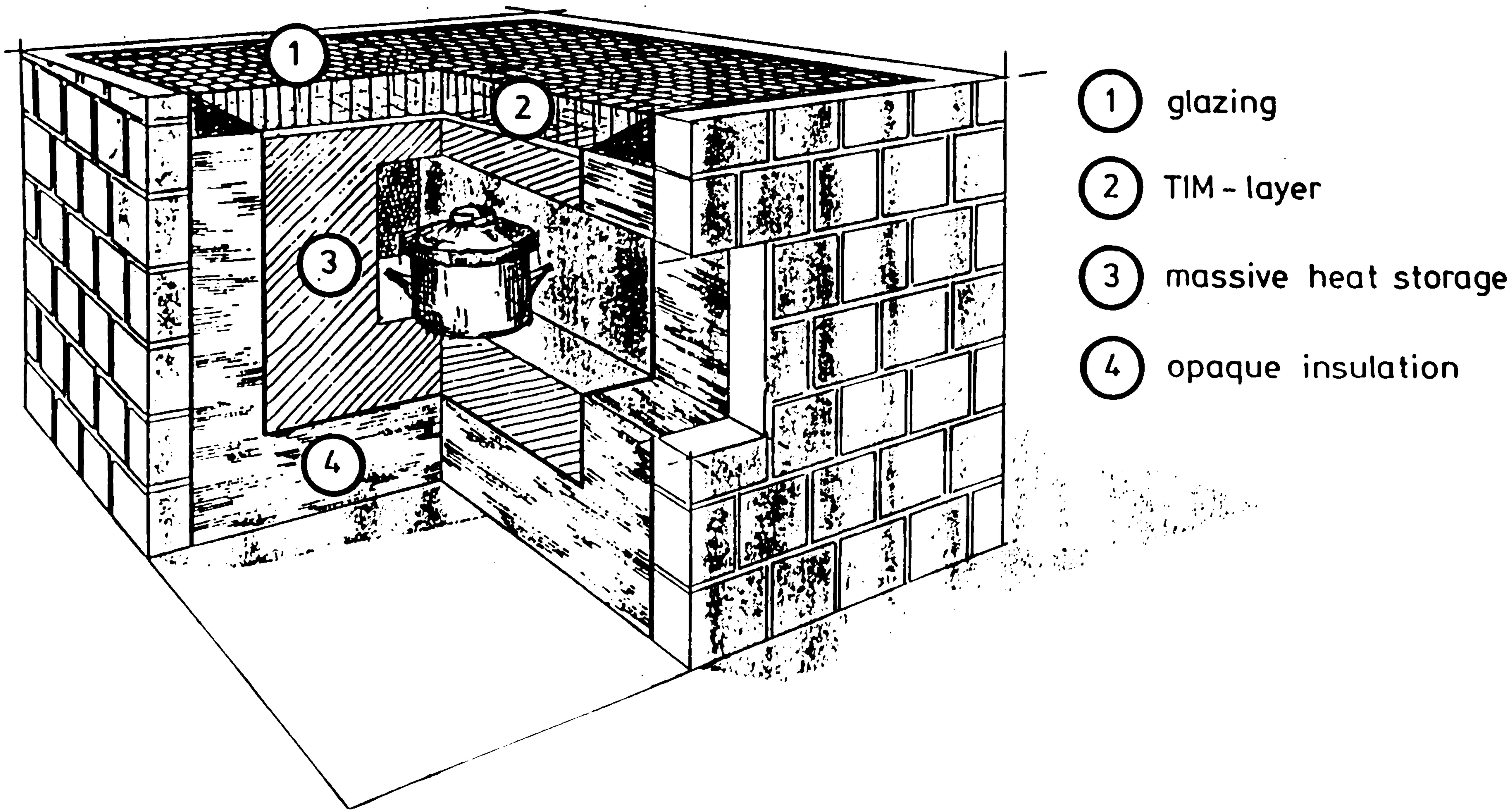
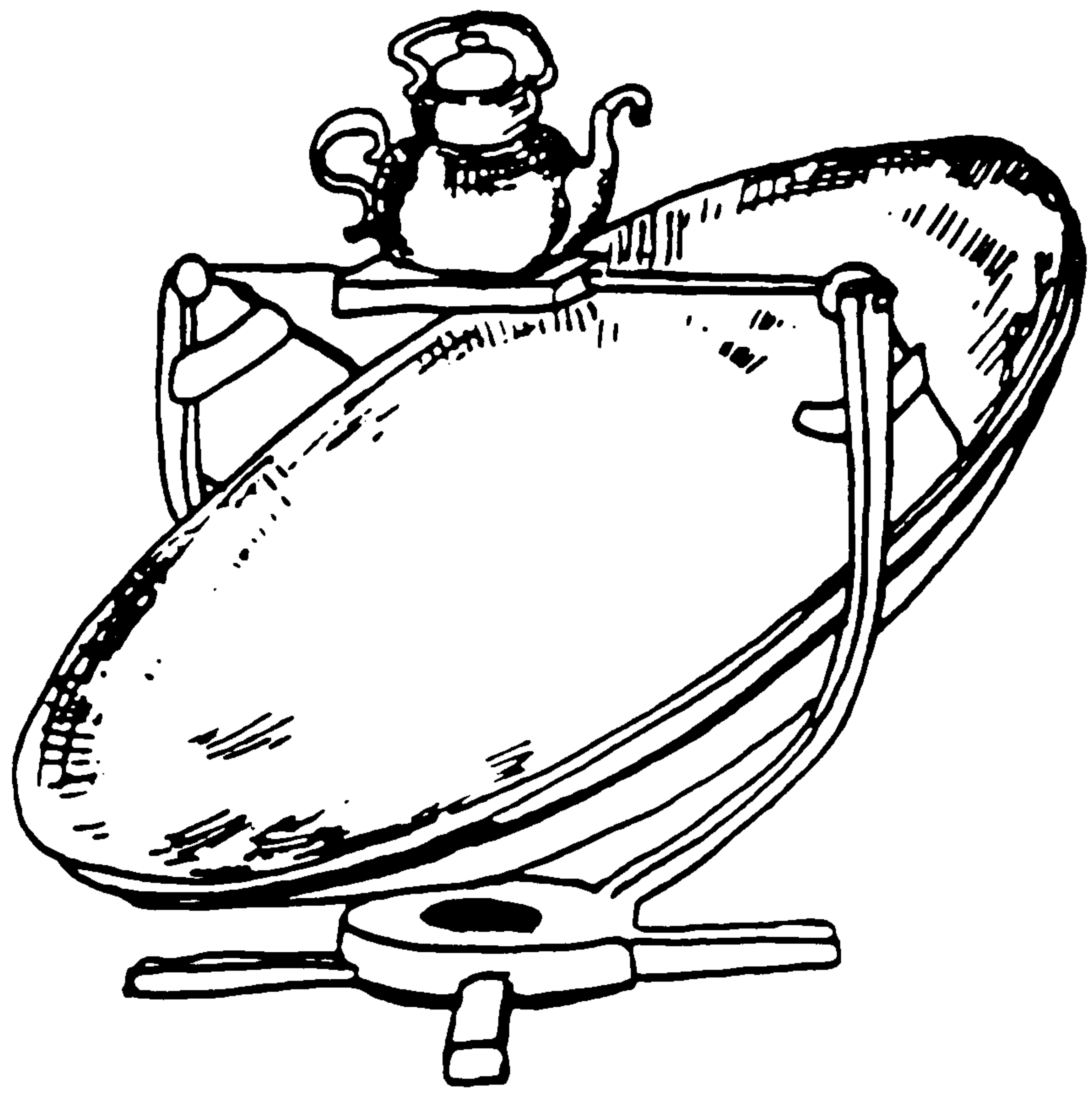


Figure 4.6 Sketch of a Solar Storage Oven.

There are many different designs of concentrating cookers although almost all designs developed are based on the use of a parabolic dish reflector measuring 0.5-1.0 metre in diameter which, when directed at the sun, reflects and concentrates solar radiation on to a central platform (raised above the reflector's surface) on which the cooking vessel is placed [54]. This is illustrated in figure 4.7. Vessels designed for use in solar cookers are generally of light-weight construction with a matt-black finish and a well-fitting lid in order to maximize solar radiation absorption.

4.11.4 PHOTOVOLTAICS.

Photovoltaics (PV) is a technology that can convert photons of light directly into electricity. PV is a result of the phenomenon called the photovoltaic effect, whereby both current and voltage can be generated by the absorption of light in a non-uniform semiconductor material. The non-uniformity is usually derived by doping one face of a p-type silicon wafer to form a thin n-type layer or by depositing an n-type material on to a p-type material. These devices are often called solar cells. A typical solar cell is 10cm by 10cm in size and will generate around 3.5A at 0.5V in full sunlight. Solar cells are connected together and packed into modules capable of generating around 60 watts of electricity, and modules are connected together to generate larger quantities of electricity using only the sun as the fuel source.



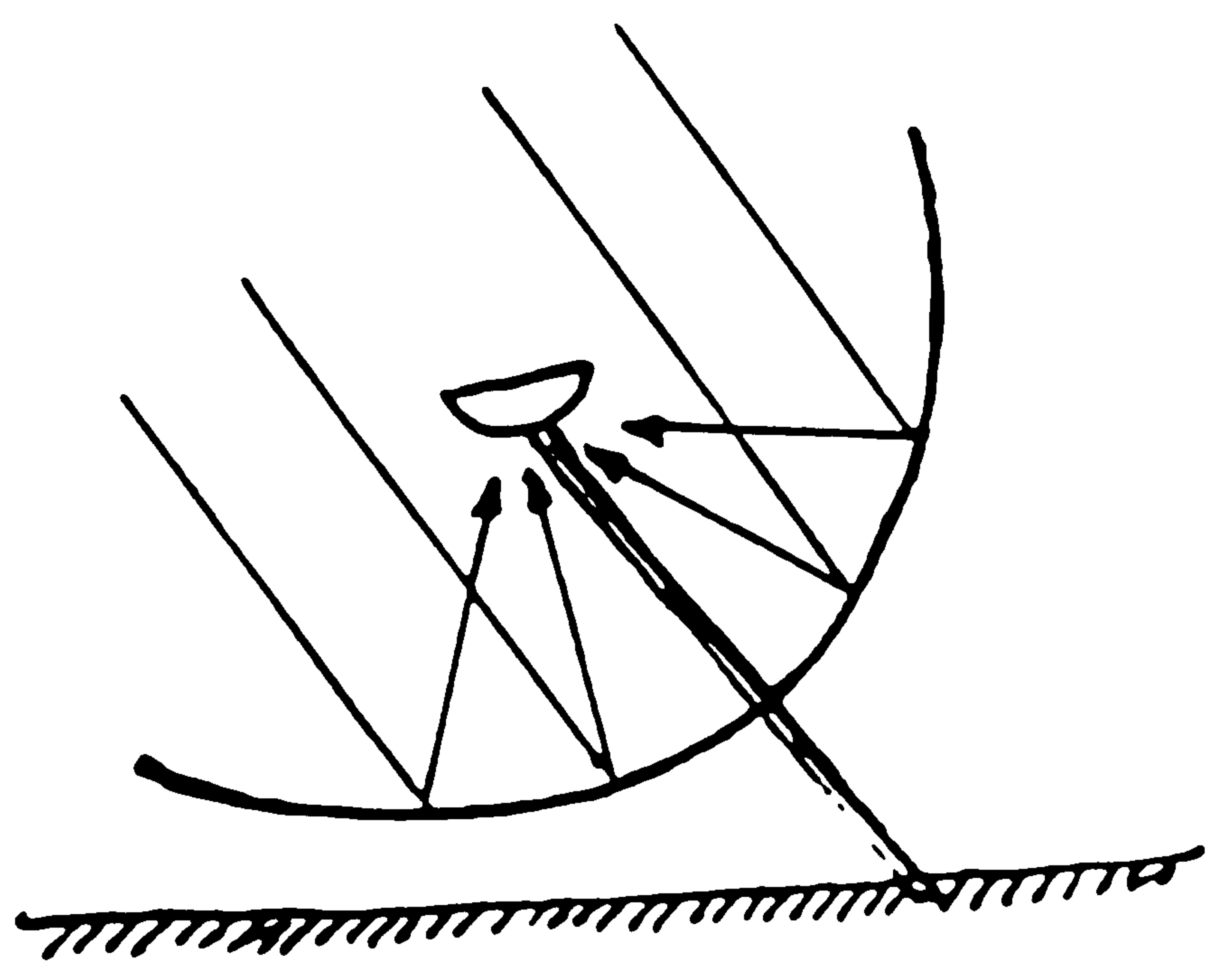


Figure 4.7 Concentrating Solar Cooker [30]

PV systems are being used in developing countries to provide power for water pumping, lighting, vaccine refrigeration, electrified livestock fencing, telecommunications, cathodic protection, water treatment and many other applications [55]. Some PV applications in the Gambia have been very successful [23][56].

The PV cell, module and array production require sophisticated and expensive equipment plus a high level of technical ability. Since most developing countries possess neither the funds nor the expertise to produce their own PV systems, only a few developing countries (like India and Brazil) have local production capabilities. As a result, PV systems used in most areas of the developing world are imported and so attract associated high import duties, consequently raising the price of PV systems in these areas significantly.

4.11.4.1 Semiconductor Solar Cell.

When a photon at an appropriate energy level frees an electron, or removes it from a stable state, it gives all its energy to the process and ceases to exist as an entity. The free electron now possesses all the energy of the photon minus the energy used in freeing it. Two entities have in fact been created: a free electron and a "hole" which is an effectively positively charged entity resulting from the absence of the electron from its original site. The free electron and the hole can move within the semiconductor. The separation of the negatively charged electrons and the positively charged holes will generate a voltage, whilst the movement of these electric charges constitutes a current. In this way both current and voltage are generated simultaneously and so electrical power can be delivered to an external load.

Basically a solar cell is a semiconductor diode, so constructed that light can be absorbed into the region of the p-n junction. A typical solar cell is shown in figure 4.9. Silicon is one of the most commonly used semiconductor materials in fabricating commercially available solar cells. Certain impurities deliberately introduced into the silicon give rise to excess negative or positive charges which can carry electric current in the silicon.

This process is called doping. If boron atoms are introduced into the silicon, the atoms soak up electrons from the silicon leaving holes (missing electrons) which behave like excess positive charges (p- type silicon). A p-n junction could be formed close to one surface, by allowing phosphorus to diffuse into the surface of a p-type single crystal wafer and the p-n junction provides the electric field which give rise to the diode characteristics as well as the photovoltaic effect. Excess electron hole pairs are created when silicon material absorbs light. Each electron hole created is caused by the absorption of a photon. If this occurs near the p-n junction, the electric field present there will act to separate the holes from the electrons, causing the holes to build up in the p- type material and electrons in the n- type material. These excess charges generated by the light and separated by the junction can be made to flow through an external circuit by connecting electrodes to the p- and n- type regions. The flow of electrons and holes constitute a current. The potential difference across the electrodes and the current flow would provide power to an external circuit or load.

Photons with energy, hf (h = planck's constant and f = frequency of photon), greater than the energy gap (Eg) and also absorbed by the semiconductor will result in the creation of electron hole pairs. Hence the number of photons with energy greater than the energy gap, Eg, (this is the energy needed to excite the electrons from the valance band to the conduction band) decreases with the depth from the front surface. Since the solar spectrum is very broad and the absorption constant is a function of wavelength, the composition of photon flux varies with depth. Most of the shorter wavelength photons are absorbed near to the front surface, while the absorption for longer wavelength photons is less and hence they penetrate deeper into the cell. Figure 4.8 show graphically how the absorption coefficient of silicon and other PV materials varies with wavelength. The minimum thickness required for complete absorption of photon energy greater than Eg is 400 microns for silicon [57]. For a cell thinner than the minimum thickness, the photons will pass out of the cell from the back surface if it is not completely covered with metallic contact or else they will be reflected and on their way back to the front surface, some of the photons will be absorbed and

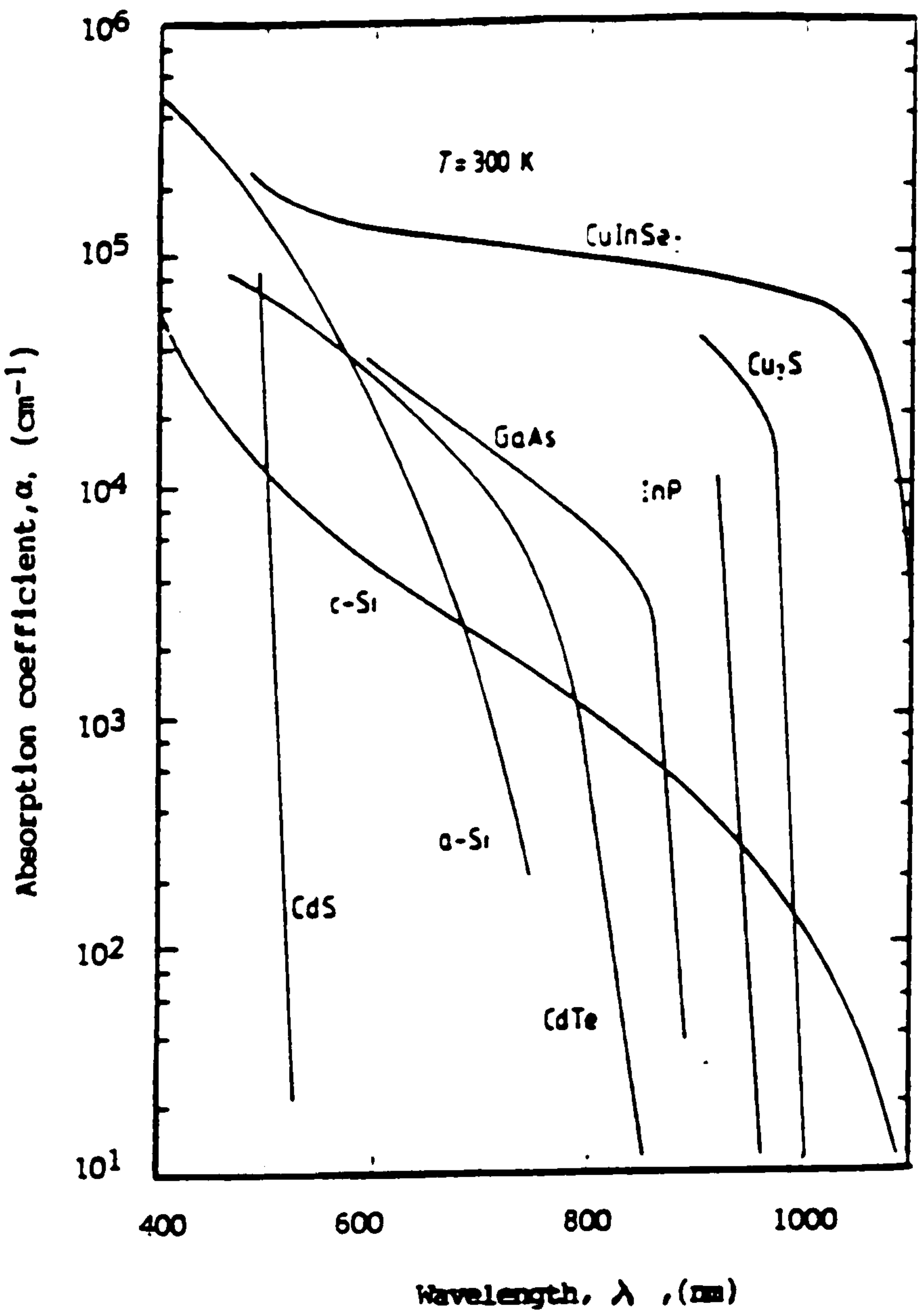


Figure 4.8 Absorption Coefficients for various Semiconductors used in PV Energy Conversion [58]

the rest will be transmitted out of the cell. The minority carriers generated diffuse randomly and some will be swept across the junction on reaching the depletion region, resulting in the photogenerated current. The rest will recombine and hence do not contribute to the light current.

The first solar cell was developed by Chapin, Fuller and Pearson in 1954 obtaining an efficiency of 6% for a silicon single crystal cell [59].

4.11.4.2 Solar Cell Configuration.

Shown in figure 4.9 is the cross section and plan view of a silicon n-p homojunction solar cell. Also shown in figure 4.10 is the geometry of the silicon solar cell. The cell consists of a slice of single crystal silicon 200 to 400 microns thick. The cell thickness is often governed by capacity to absorb light.

An n- type layer 0.1-0.5 microns thick is diffused and finally the cell is contacted and the antireflection coating applied, reducing reflection from the surface of the cell. The junction is formed by a diffusion of phosphorus (P), typically from a compound such as PH_3 (phosphine) in a carrier gas. Oxygen is often added to this gas so as to prevent the formation of a dead layer.

The back is usually aluminium deposited by vacuum evaporation or screen printing. A heat treatment is used to diffuse in a portion of the aluminium, making a P+ layer that lowers the contact resistivity and can, if sufficiently thick, produce a back surface field to

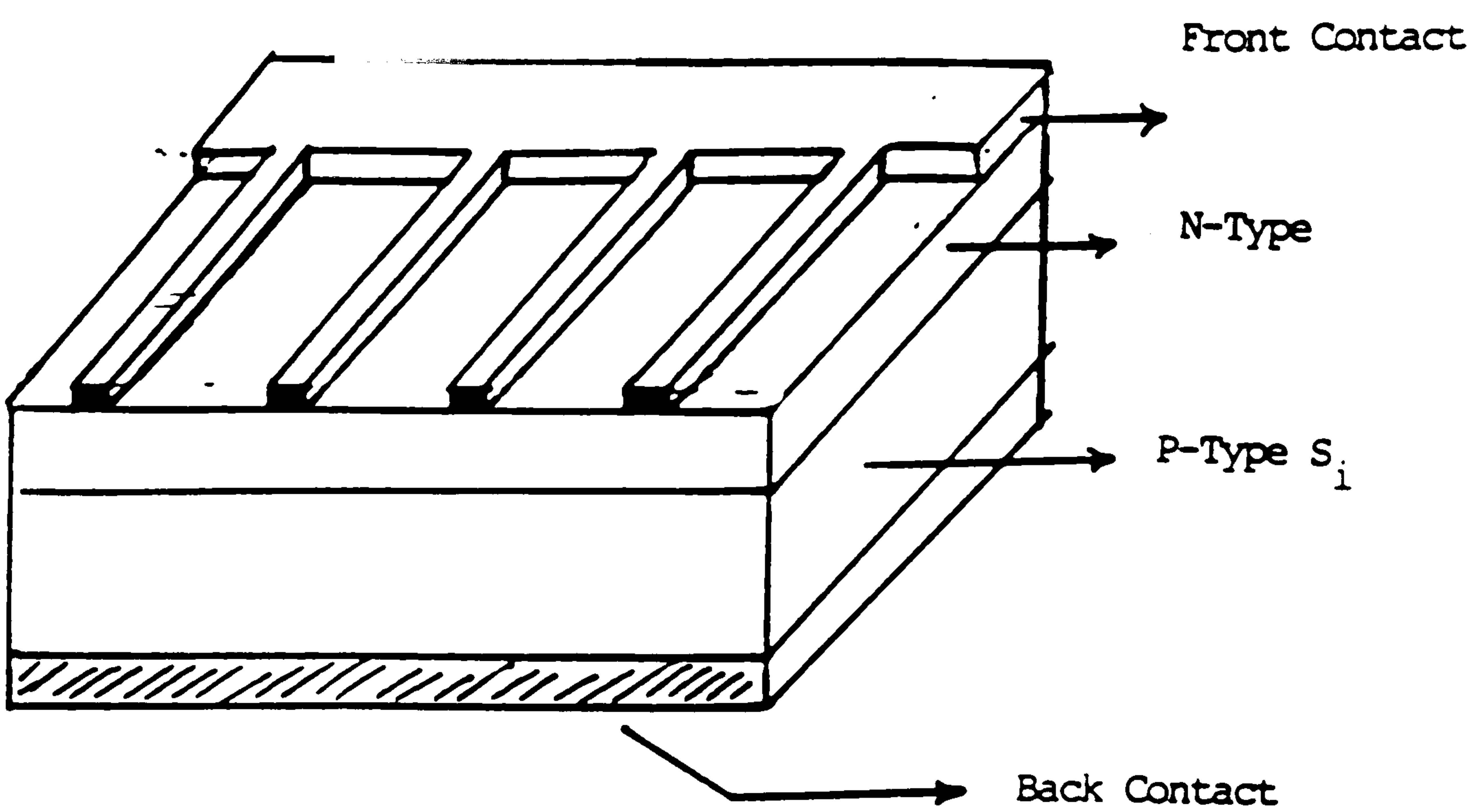


Figure 4.9 Diagram of a Silicon p-n Solar Cell.

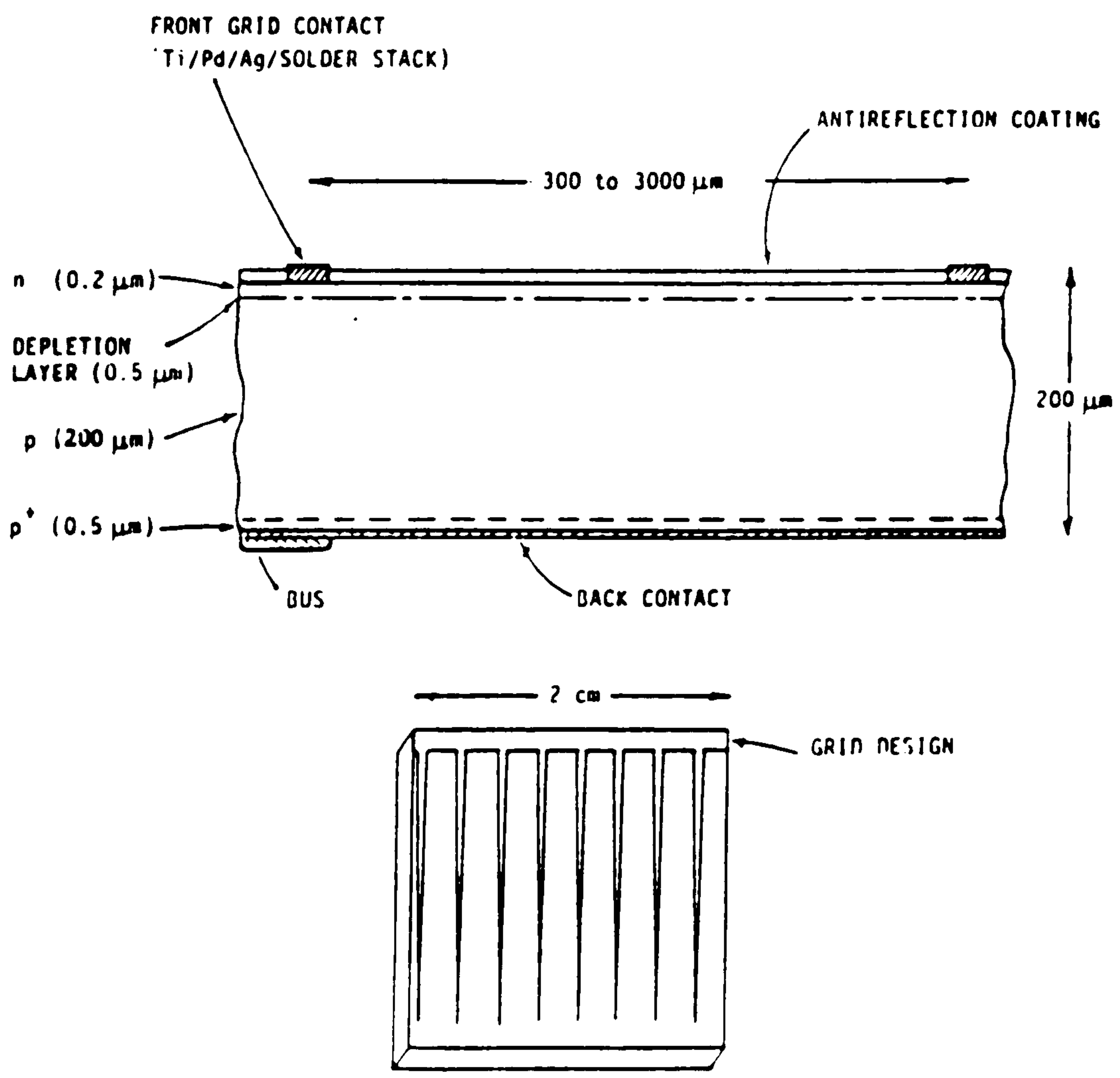


Figure 4.10 Silicon Solar Cell Geometry.

reduce the effect of surface recombination. The antireflection coating is made from layers of SiO, SiO_2, Si_2N_4, Al_2O_3, TiO_2 or Ta_2O_5, the last of which is good for use in ultra-violet transmission. The use of surface texturing is also used to reduce reflection. Ohmic contacts are made at the front and rear surface of the cell.

4.11.4.3 Solar Cell Parameters.

There are three parameters that are used to describe the performance of the solar cell. These parameters are given below:-

(1) Open Circuit Voltage (Voc).

The open circuit voltage is the potential difference across the contacts of the illuminated diode when the internally generated illumination current is balanced by the forward current due to the photovoltage. It can also be expressed as the output voltage when the load impedance is very much greater than the device impedance.

(2) Short Circuit Current (Isc).

The short circuit current is the current through an external load when no externally applied bias is present. It is equivalent to the illumination current Iph. It is sometimes referred to as the current flowing in the output when the load impedance is very much less than the device impedance.

(3) The Fill Factor (FF).

This is the ratio of maximum power output to the product of Voc and Isc and it can be determined by the rectangular area shown on the diagram of the I-V characteristic in figure 4.11. It is a measure of the "squareness" of the I-V characteristics or of the reduction of voltage and current at the maximum power point compared with the open circuit and short circuit conditions.

The equivalent circuit of the solar cell is shown in figure 4.12. If the load resistance R_L is disconnected (R_L=infinity), the cell develops an open circuit voltage Voc. When R_L is short circuited (R_L=0), the cell generates the short circuit current Isc=Iph, which is determined by the spectrum of the light source and the spectral response.

The fill factor is usually given as:-
FF = (Im x Vm)/(Isc x Voc), where Im and Vm are the maximum current and voltage obtained from the cell using an optimum load.

4.11.4.4 Solar Cell Materials.

Many semiconducting materials have shown some PV properties. These materials are in single/poly crystalline form or thin film devices.

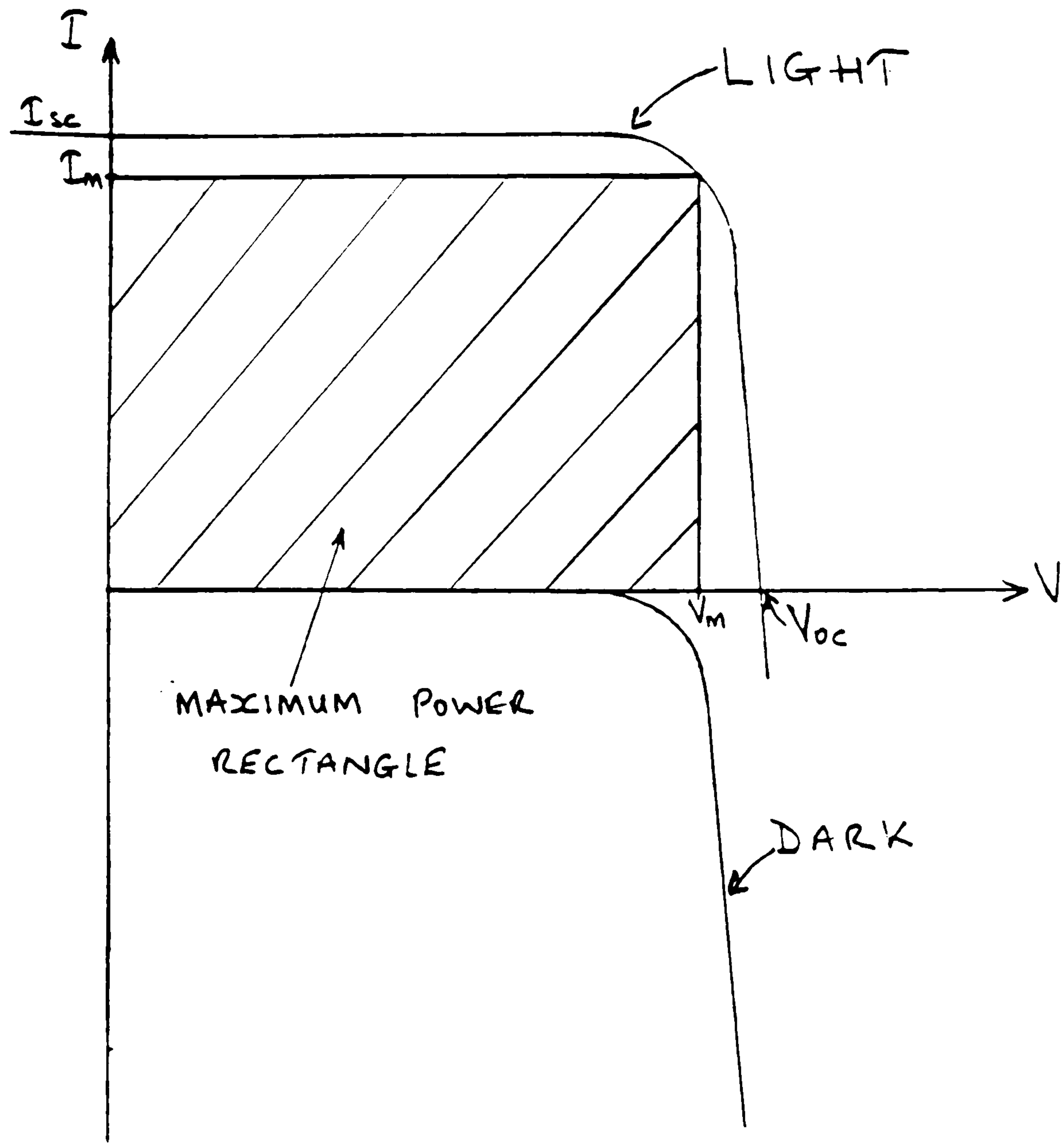


Figure 4.11 Ideal I-V Characteristics of a Solar Cell.

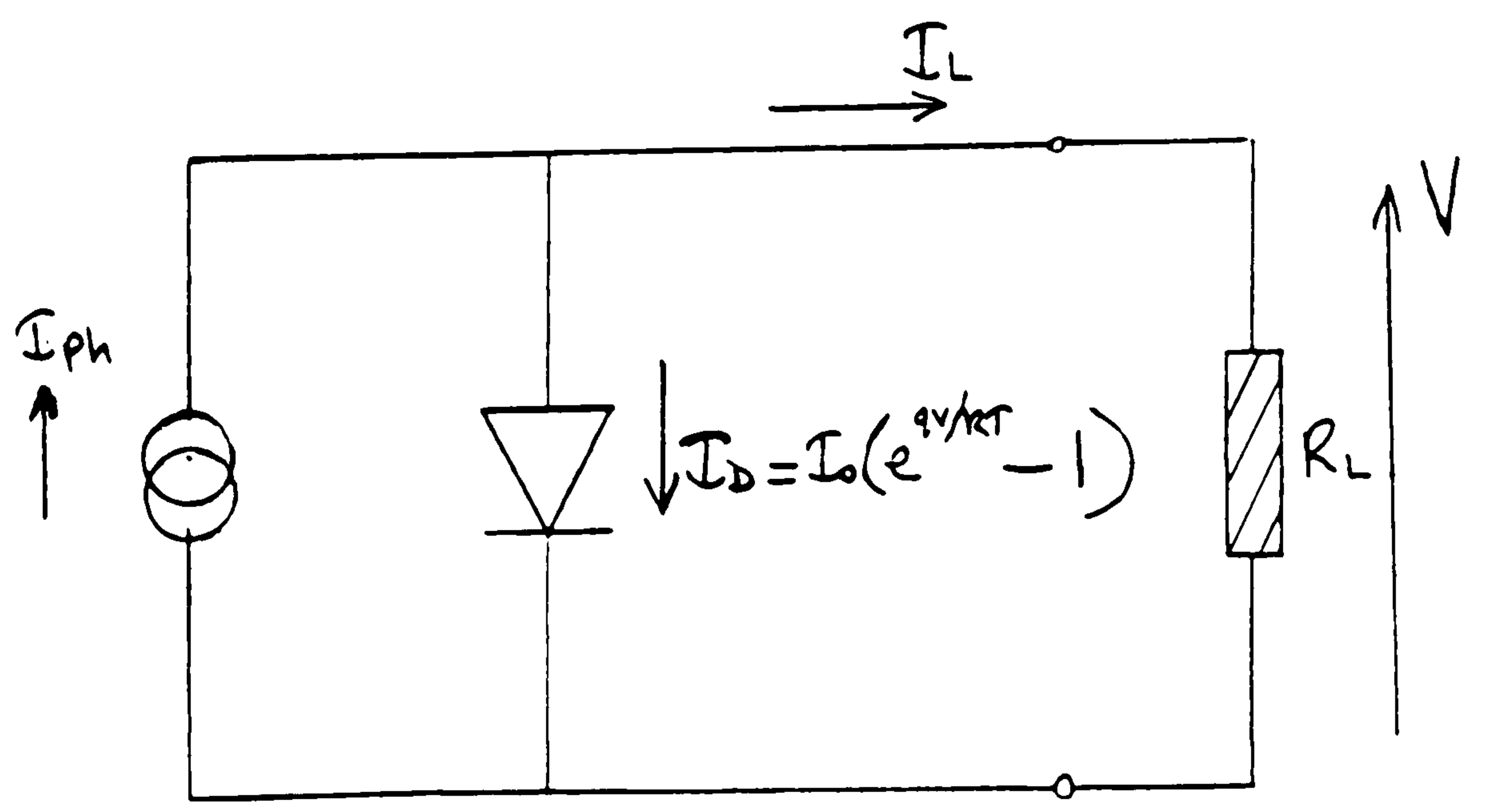


Figure 4.12 Equivalent Circuit for the Ideal Solar Cell.

(1) Crystalline Devices.

These devices include silicon, gallium arsenide (GaAs) and indium phosphide (InP).

Crystalline silicon is used for both space and terrestrial applications. It has a module and device efficiency of up to 20% and 24% respectively [60]. Commercial modules currently available have efficiencies of 15% with a cost of about of \$3.50 - \$4.50 per Watt peak (Wp) at a solar irradiance of $1kW/m^2$. To reduce the cost of production of silicon solar cells and modules [61], poly-crystalline material is used with module efficiency of about 14% and cost about \$3.00 - \$4.00 per Wp.

GaAs and InP are more resistant to "radiation damage" hence more applicable to providing power to space-craft [62]. These solar cells have been found to decrease in efficiency when heated much less than silicon solar cells which are found to degrade in efficiency at about 0.5% per ^{o}C. Thus GaAs solar cells can be used in a "concentrator system" [63][64]. The highest efficiency device ever produced uses a GaAs p-n junction with a gallium antimony (GaSb) p-n junction beneath it in a so called "tandem arrangement"; this device has an efficiency of about 38% in concentrated sunlight [65]. The highest reported efficiency for InP is 21.9% on a $4cm^2$ total area [66].

(2) Thin Film Solar Cells.

These solar cells are made from semiconductor materials with a direct energy bandgap and such materials are over ten times more absorbent for visible light than crystalline silicon. Thin film material is normally deposited on a low cost substrate, such as glass, metal or plastic, with a thickness of a few microns or less (usually about 1 μm). The major materials that are currently considered for thin film solar cells with future potential are mentioned below:-

(1) Amorphous silicon (a-Si) Solar Cell.

This solar cell is used as a commercial device, integrated into pocket calculators, clocks, watches, etc. It has an efficiency of about 8% and the efficiency of such device degrades when illuminated due to the so called "Staebler-Wronski effect" [61][67]. The stabilisation of these devices using multi junction (or tandem) structures has been reported but the more complex structures used add to the cost of manufacture and reduce the yield of the production processes for large scale manufacture. The highest efficiency reported for the tandem structure is about 12% [66].

(2) Copper Sulphide (Cu_2S)/Cadmium Sulphide (CdS) Solar Cells.

Cu_2S/CdS was one of the earliest heterojunction thin film solar cells developed. The attractive feature of these cells was their ease of fabrication and this was of commercial importance. Efficiencies obtained were about 5% to 9% in pilot production [68].

Cu_2S/CdS had major instability problems as a candidate for commercial solar cell device production. These problems were oxidation and phase instability of the Cu_2S under high humidity conditions resulting in the reduction of short circuit current, open circuit voltage and fill factor. After substantial research efforts, the device degradation with time was still not solved, so it did not find wide application [67].

(3) <u>Cadmium Sulphide (CdS)/Cadmium Telluride (CdTe) Solar Cells.</u>

Polycrystalline CdTe has an energy band gap of 1.44eV which is near the optimum of 1.5eV for solar cell energy conversion and a high absorption coefficient of the order of 10^4 - 10^5 cm^{-1}, (see Figure 4.8). An efficiency of 15.8% with area of $1cm^2$ [69] has been reported in 1993.

Typically CdTe and CdS films of a few microns in thickness are usually required for device fabrication. One of the advantages of CdTe solar cells is that they do not require the complex structure or triple junctions to achieve high conversion efficiency. In spite of the simplicity in the manufacture of CdTe solar cells, the difficulty of forming a good and stable ohmic contact to the p-CdTe is still to be overcome. This problem has been addressed by Photon Energy Inc, by introducing 10 μm of graphite between the CdTe and the metal back contact.

However, because of promises of a simple manufacturing technology, high efficiency and low cost process, research is geared towards commercialisation of CdTe by Matsushita, Photon Energy, BP Solar and Solar Cell Inc.. Matsushita has produced CdTe solar cells by screen printing for low light applications.

(4) **Copper Indium Diselenide ($CuInSe_2$) Based Solar Cells.**

$CuInSe_2$ has great prospects for large area low cost solar cell devices promising 15 - 20% efficiency [70]. Much research effort is put into the development of this material since the current emphasis in photovoltaics is directed towards thin film polycrystalline solar cell devices on an inexpensive substrate that can serve in the long term as a viable alternative to crystalline silicon. This is primarily because of their low energy processing, lower material requirements and ease of large area deposition.

$CuInSe_2$ has the highest absorption coefficient among the PV materials shown in figure 4.8. An efficiency for $CuInSe_2$ based solar cells of 17.6% have been reported in 1994 [62][71].

The drawbacks associated with the $CuInSe_2$ solar cells are:- the complexity of their process steps, basic material properties, interface interactions/stability, relatively expensive cost of indium and toxicity associated with the manufacturing process. However, despite the limited knowledge of the material properties, $CuInSe_2$ remains a good material for a polycrystalline thin film approach for PV power generation because of its potential for a large area low cost process method and the stability of large area modules under illumination.

4.11.4.5 The Influence of Solar Irradiance Intensity and the Temperature on the Output of PV Module.

The solar energy available at any place on the earth's surface depends upon the latitude, the season of the year and the time of the day. Clouds, fog and atmospheric pollution can cause daily and hourly variations, reducing the intensity of the radiation received. The intensity of solar radiation on a flat surface is higher when it is tilted towards the sun. The maximum intensity occurs when the flat plate surface is perpendicular to the sun's rays. Generally, for the maximum absorption of solar energy over the course of a year, fixed flat plate collectors should face the equator and be tilted from the horizontal by an angle about equal to the angle of latitude.

Figure 4.13 illustrates the influence of irradiance on the PV current and voltage output characteristics at constant cell temperature. At a low level of irradiance, the short-circuit current (Isc) is proportional to the solar irradiance (neglecting the series resistance at high irradiance and shunt resistance at low light levels). It is of the order of 30mA cm^{-2} for an irradiance of $1kWm^{-2}$ for a single crystal-silicon cell (at temperature = $25^{o}C$). The open-circuit voltage (Voc) increases slightly with increasing irradiance. It is of the order of 590mV for $1kWm^{-2}$ of irradiance for a single-crystal silicon cell (at temperature = 25^oC).

The short-circuit current varies greatly with the irradiance level, whilst the open-circuit voltage variation is extremely slight. This is because the photocurrent (Iph), and hence the short circuit current in the ideal cell, is a linear function of illumination flux. The open-circuit voltage is a logarithmic function of the irradiance level.

The relationship between current and voltage at the maximum power point is also shown in figure 4.13, by an almost vertical line. The voltage at the maximum power point remains nearly constant at any irradiance level. The evaluation of the maximum-power line is important in the interest of designing the components of a PV system, so as to maximize power extraction from the modules.

The effect of temperature on the I-V characteristics is illustrated in figure 4.14. The Voc decreases with increasing temperature. The module reverse saturation current, which increases sharply with increasing temperature, causes Voc to drop whereas Isc increases slightly with increasing temperature. The overall result of these variations is a reduction in the efficiency with an increase in temperature [72].

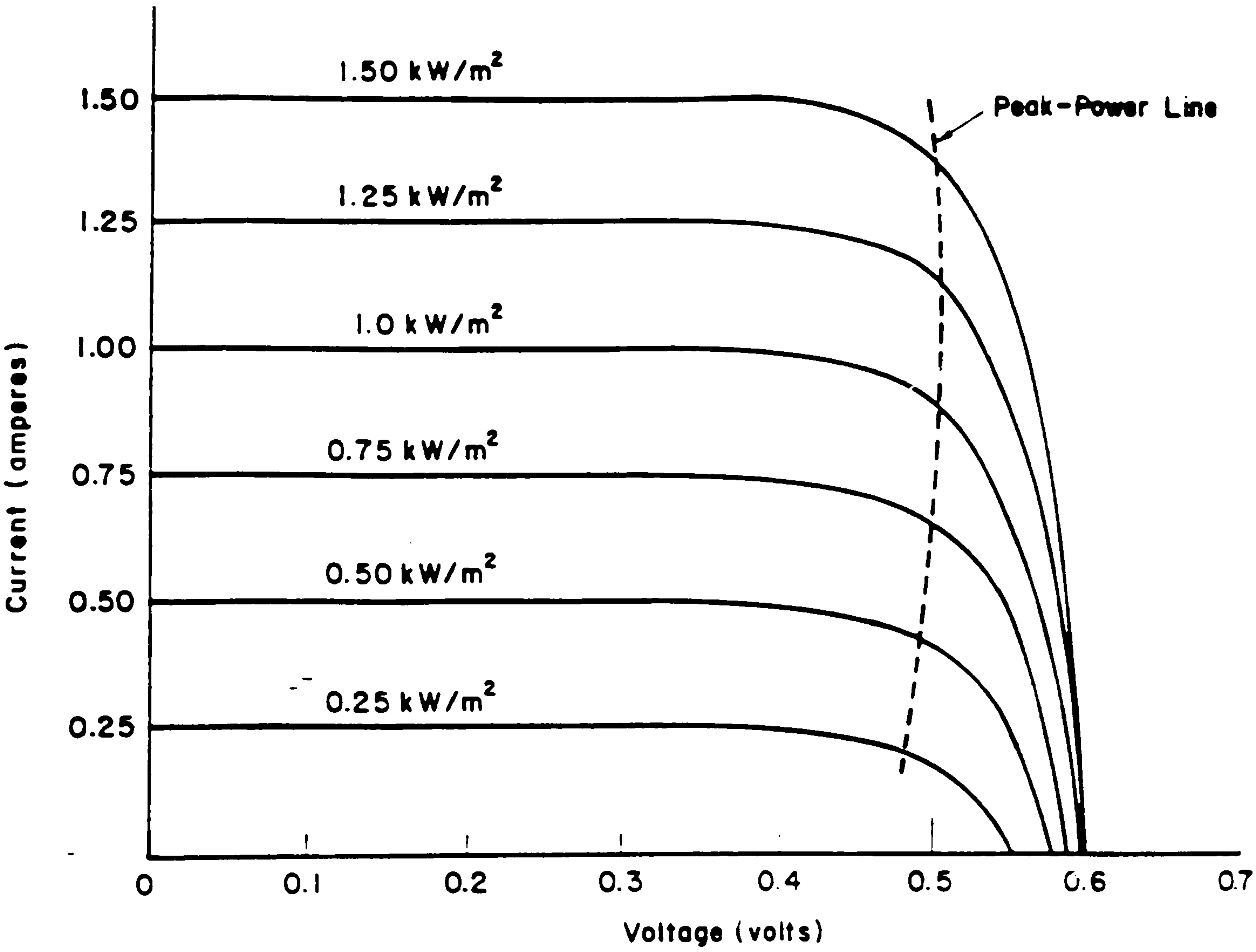


Figure 4.13 Influence of irradiance on the PV current and voltage output characteristics at constant cell temperature [73]

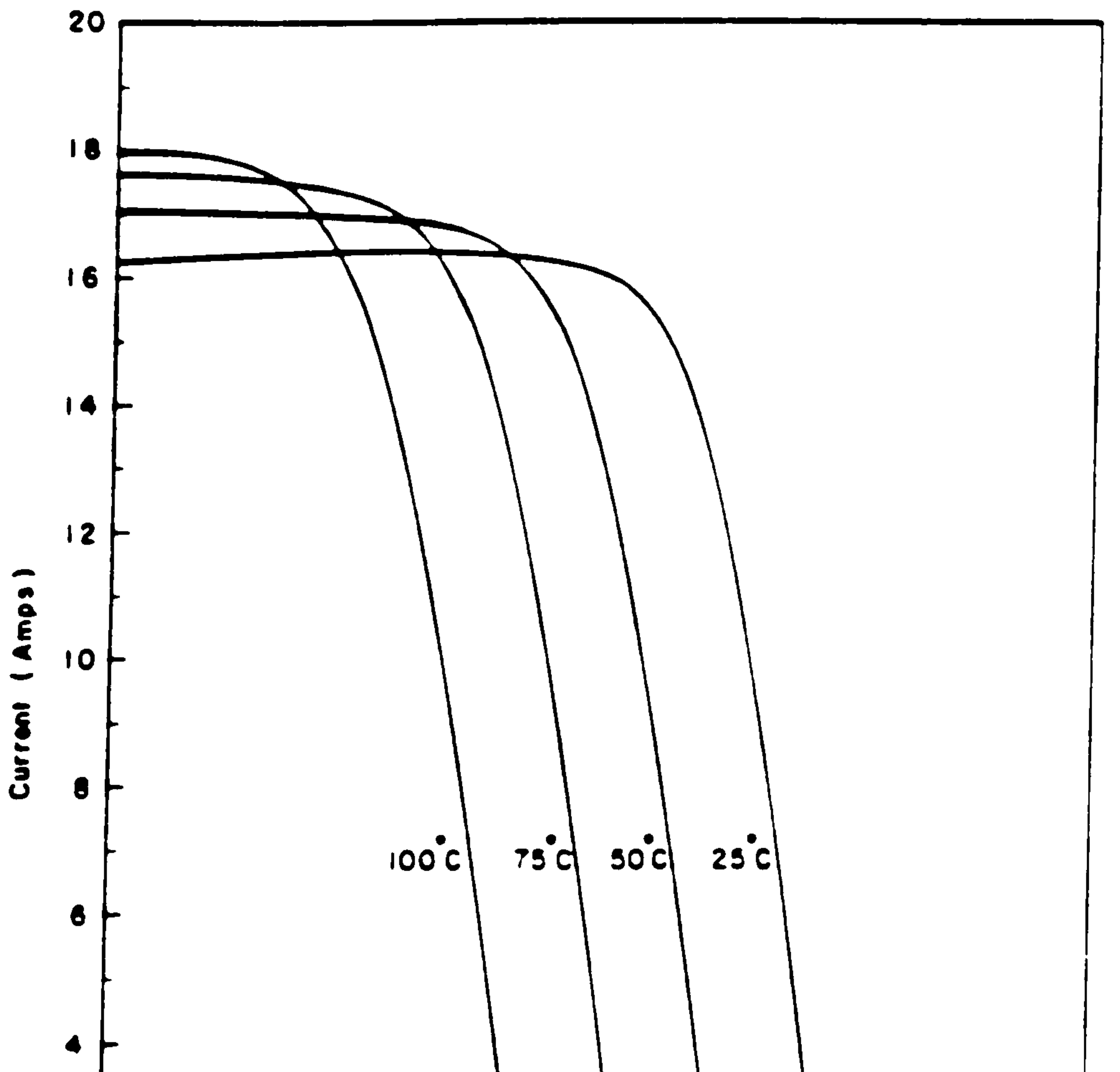


Figure 4.14 I-V characteristics at $1kW/m^2$ of irradiance for different temperature levels [73]

4.11.4.6 Cost-Effective Solar Cell Device for The Gambia.

At the present moment there are very limited solar cell devices to choose from for power supply in the Gambia. The most likely candidates are single or poly crystalline silicon, GaAs for concentrator systems and amorphous silicon. Amorphous silicon solar cells are not recommended because:-

(1) of its degradation effects. The efficiency could drop by 30 to 40% of its initial value, which could create future energy demand problems;

(2) of uncertainties about its life-span performances;

(3) it takes up about three times more land area as compared to crystalline silicon for the same amount of power output;

(4) the energy costs could end-up being higher than that of other solar cell devices.

GaAs for concentrator systems could be used in areas where the energy demand is large. Water could be used as a coolant and the heated water used in hot water systems. The energy cost looks attractive as compared to crystalline silicon solar cells.

The crystalline silicon solar cell is the best option at the moment. It has proven to be reliable, although its energy cost is a bit high. Its efficiency drops slightly with increase in temperature. If used, it should be installed in a well aerated area. It is important to purchase PV modules that conform to the international standards such as those proposed by the

International Electro-technical Committee (IEC), based on existing US, European and Japanese standards.

Apart from a-Si, thin film devices are not in proper commercial production as yet. They look very promising in terms of energy cost and stability. It is hoped that in the next 5-10 years we will be able to buy much more cost-effective commercially produced CdS/CdTe and $CuInSe_2$ solar cells.

4.12 CONCLUSION.

The integration of trees into farming practices and growing of different tree species that are ecologically and culturally compatible with local practices does hold a great potential for the Gambia. A well conceived agroforestry intervention could achieve an increased production of wood and at the same time address many of the problems related to land productivity and sustainability. The growing of energy crops does supplement existing energy supplies.

There is potential in using wastes and residue for energy production. The economic viability of using waste and residues for energy purposes depends very much on the specific waste and the purpose for which it is being used.

The production process of charcoal needs to be improved to a much higher efficiency whilst alternatives to charcoal are being established. Improved technologies could make substantial impact on reducing the amount of wood required to produce the same quantity of charcoal.

Draught animal power can have significant impact on the increased production and improved quality of agricultural products. Presently the use of animal power is an economic and appropriate form of technology. This process transforms agricultural practices from human labour-based operations to those based on the use of draught animals. It also improves the transportation situation in the rural areas.

Hydro power is very site-specific and some parts of the river Gambia with flow rates of about 2 m/s and above could be used for the production of useful energy. The Gambia is flat and is not suitable for the production of energy from dams.

Windpower does not have much potential in the Gambia at the present moment until novel generators are made operating on very low wind speeds of 2m/s or less. It is possible that there may be unidentified sites in the Gambia with quite high average monthly wind speed of 6m/s or above. This will make wind power generation cost-effective.

Solar water heaters in the Gambia have the potential to displace a significant amount of high-cost imported oil provided industries like the hotels are made aware of its potential savings. Passive cooling is an area that could help reduce the demand for electricity by air-conditioners during the summer seasons. The prospects for PV in the Gambia are very good and it is currently providing valuable energy services cost-effectively. Thin film solar cells seems to have a bright future, in terms of obtaining low energy cost solar cells.

This review of renewable energy sources has attempted to map the capabilities of these sources on to the needs for energy services identified in the end-use analysis presented in chapter three. There could be significant benefits for the Gambia in using the renewable technologies identified. The purpose of this study is to elucidate the role of PV in the Gambia and the means whereby the technology can be promoted. It is clear from this review that PV has an important part to play in the social and economic development of the Gambia particularly in health care, education and agriculture. PV could aid in the improvement of the quality of life in both the rural and urban areas of the Gambia. It is also capable of making a significant contribution to the day time electricity demand in urban areas. It can be seen therefore as one of the key technologies for the future of the country.

CHAPTER 5.

5.0 PV FOR HOUSEHOLD & COMMUNITY APPLICATION.

This chapter will discuss some PV applications that are technically and economically beneficial to the Gambia. Technical performance, reliability and cost estimates have been assessed for the following:-

(i) PV lighting system for domestic and educational use - this is a social service for economic development by increasing the length of the productive working day and countering population drift from villages to cities.

(ii) PV water pumping system for domestic and agricultural uses - this is a major social benefit, providing clean drinking water and alleviating the effects of drought.

(iii) PV medical vaccine refrigeration system - this is a health benefit, immunizing the population against diseases and hence ensuring a healthy nation for socio-economic development.

5.1 PV SYSTEM SIZING & ECONOMIC ANALYSIS.

The rate of change of solar irradiance and the load to be powered are quite important factors for consideration in PV system sizing. This in turn also affects the system cost and the life cycle economic analysis. Some of these considerations are given below.

5.1.1 SYSTEM SIZING.

To size a solar system [72], it is essential to have accurate information about the load to be supplied and the best available radiation data for the intended site [74]. For the Gambia, the average daily global radiation on a horizontal surface is $5.5kWh/m^2$.

The total battery capacity can be calculated when the depth of discharge due to seasonal fluctuations is selected. Since the reserve capacity (CR) should be available even when the battery is at its lowest state of charge due to seasonal variations, the total capacity required is CR/(1-D), where D is the fractional depth of discharge desired.

The size of the PV panels can be determined from the average insolation and energy demand, since

$Ppk = (Wel/Wr)*1kW/m^2$.

Where Ppk is the measure of the size of a solar generator in kW peak, defined as the output power of a solar generator at an irradiance of $1kW/m^2$, Wel is the electrical energy demand in KWh per day and Wr is the radiated solar energy in kWh per m^2 per day.

The efficiencies of the battery control unit (BCU), batteries, inverter and matching should be included as well. It is assumed that all generated power is passed on to the load via batteries. The size of the generator will be determined by:-

$$Ppk = \frac{Wel}{Wr*Nb*Ninv*Nm*Nbcu} * 1KW/m^2.$$

where,

Nb = Battery efficiency

Ninv = Inverter efficiency

Nm = Matching efficiency

Nbcu = BCU efficiency

5.1.2 METHODOLOGY OF ECONOMIC ANALYSIS.

Economic considerations are important when comparing photovoltaics with other conventional power sources. PV systems are technically viable but where alternatives exist, the evaluation of the alternatives must include economic, technical, social and environmental considerations.

A complete approach to economic appraisal is to use life cycle costing because all future expenses are then taken into account. In this method, all the future costs and benefits are discounted to the present worth (PW) or "present day values". The calculation of PW involves the use of a discount rate which reflects the opportunity cost of capital. The current inflation and discount rates in the Gambia are 10 and 9.5% respectively. High discount rates mean that a low value is placed on future costs and benefits.

It is worth mentioning that such economic analysis does not take into consideration such factors as environmental benefits, where PV does not add to environmental pollution like conventional energy sources. The benefit of PV having a higher reliability factor, hence giving a superior service, is sometimes omitted.

5.1.2.1 Calculation of Present Worth.

For a future cost or benefit (Cr) [75], payable in N years, which is inflating at a fixed percentage "i" each year and discounted at a rate "d", the present worth is given by:-

PW = Cr*Pr where $Pr = [x]^N$ and x = (1+i)/(1+d).

For a payment or benefit (Ca) [75], occurring annually for a period of N years which is inflating at a rate "i" per year and discounted at a rate d, the present worth is:-

PW = Ca*Pa where $Pa = x[x^N-1]/[x-1]$ and x = (1+i)/(1+d).

For The Gambia, the factor Pa is calculated for a payment or benefit occurring annually during a period of 25 years with an annual inflation and discount rates of 10% & 9.5% respectively, as 26.54 [76].

5.2 PV LIGHTING APPLICATION FOR THE GAMBIA.

In the Gambia, lighting is presently the largest application of PV with a few hundreds of systems installed throughout the country. They are mainly used to provide lighting for domestic or community buildings, such as schools or health centres. Unfortunately, the majority of Gambians are unable to acquire systems, mainly because of their capital cost.

5.2.1 PV HOUSEHOLD LIGHTING SYSTEM VERSUS KEROSENE LAMPS.

The main source of light in unelectrified households in the Gambia is kerosene lamps. Households generally have 2 to 4 lamps that are used from 4 to 6 hours per day on average. Kerosene use is estimated to be about 0.3 litre per day, which is equivalent to 110 litres per year, with large households using a greater amount. However, the quantity of light from a kerosene lamp is uneven and the quality of light insufficient for activities such as reading and studying. They present health hazards due to noxious fumes emitted and a fire hazard. They also produce a lot of heat and, in a hot climate like the Gambia, it feels uncomfortable in a room with a kerosene hurricane lamp. They have the lowest purchase price, but are expensive and inefficient to run.

PV lanterns and household lighting systems provide considerably more light than kerosene lamps, as well as better quality light. These lanterns have proven to be economically viable in other parts of the world and are an important potential application for PV [77]. In comparison with kerosene lamps, the convenience, relative safety and better quality of the electric light is generally accepted as preferable. The use of fluorescent lamps rather than filament lamps is necessary for efficient use of the electricity. The power and efficiency of the kerosene hurricane lamp and the PV lamps are given in table 5.1 [75].

TABLE 5.1: LAMPS - POWER & EFFICIENCY.

Type of Light	Energy Source	Intensity (Lumens.)	Power Use Effic. (Lumen/Watt)
kerosene lamp (wick-100W).	kerosene	10	0.10
PV filament lamp (40W).	electricity	400	10
PV fluorescent lamp (15W).	"	600	40
PV fluorescent lamp (20W).	"	1000	50

The size of the potential market depends on the number of households with sufficient income to purchase the system with cash or credit, and the availability of appropriate financing mechanisms, although, on a life cycle cost basis, PV has a much lower cost than kerosene (see table 5.2). There are a large number of households, institutional and commercial establishments that are not connected to the national grid and hence are potential users of PV systems for lighting.

5.2.2 SCHOOLS - PRIMARY & SECONDARY SCHOOL LIGHTING.

A large number of schools in the Gambia do not have access to electricity and, therefore, they can only operate during the day. It is believed that having access to light and power would mean that the schools could operate for longer hours with increased capacity. Many schools in the rural areas are used for community activities like adult education. Many of these schools use kerosene lanterns and the light provided is of poor quality and insufficient for reading or studying.

Five rural schools are expected to install PV systems [78]. Schools are a potential market for PV lighting systems. However, the actual size of the market will be limited by the capital budget of educational authorities and donor agencies.

5.2.3 MEDICAL AND HEALTH CENTRE LIGHTING.

Most health centres in the rural areas are not grid connected and hence use kerosene lamps or PV lighting systems. It is planned to equip 17 health centres, 13 dispensaries and 2 mission stations in the rural areas with PV lights [78]. Quite a number of health centres are still using kerosene and candles for lighting purposes. These not only pose a fire hazard but also a serious health risk. Kerosene and candle lighting provides very poor quality light for essential medical activities such as examinations.

5.2.4 DESIGN OF PV SYSTEM FOR HOUSEHOLD LIGHTING.

The design is carried out for a household needing two fluorescent lamps for lighting purposes at night. A similar design method is carried out for a household needing more lights and/or a greater load.

Electrical load.	Total period on per day.	Total.
2 - 8W fluorescent lamp	x 4.5hrs.	72Wh

Since there is power loss resulting from the charging and discharging of the battery, which is used as a storage system to supply power to the fluorescent lamp at night and has an efficiency of 90%, the total power needed from the PV panel has to be scaled up by 20% to make up the losses.

Hence, the total power needed from the PV panel to supply the battery should be ≥ 72Wh/(90%*90%) = 89Wh.

With a minimum daily solar insolation of about 4.5KWh/m^2 in the Gambia, a 22Wp solar array (BP222SR) [79], will produce:- 22W * 4.5 sunhours daily = 99Wh.

This output power of 99Wh from the PV solar array is quite adequate to light up the two fluorescent lamps through a charged battery.

TABLE 5.2. COSTS OF PV LIGHTING VERSUS KEROSENE HURRICANE LAMP.

	Kerosene Lamp ($)	PV Lighting ($) [78]
Array, 22W_p (BP222SR).		262.50
Battery(L80,12V,80Ah).		88.50
Fluorescent lamps + fittings (2 * BL8,8W-12V).		69.00
Voltage regulator(GSR12-100,120W).		75.00
Cables, clips & battery accessories.		37.50
PW of fluorescent tubes (life=2yrs) (2 @ $1.95 each * 12.74).		49.69
PW of battery (life = 5yrs.) ($88.50 * 4.24).		375.24
PW of voltage regulator(life=8yrs.) ($75 * 3.23).		242.25
Kerosene hurricane lamp(2 @ $8.57).	17.14	
PW of fuel (219 litres @ 57¢/litre = $124.83 * 26.5).	3308.00	
PW of hurricane lamps(life=2yrs.)	218.24	
PW of wicks (life = 1yr.) (2 @ 54¢ each * 25.42).	27.45	
	-------	-------
Total Life Cycle Cost (LCC).	3570.83	1199.68
Annualised LCC (LCC/25).	142.83	47.99

5.2.5 ECONOMIC & TECHNICAL ASSESSMENT OF PV LIGHTING VERSUS THE CONVENTIONAL LIGHTING SYSTEMS.

The economic viability of PV and the conventional technology is presented, comparing the annualised costs of the two different systems (see table 5.2). The economic comparison is between PV fluorescent lamps and kerosene hurricane lamps in a Gambian context.

For an average 4.5 hour duration each day, a kerosene hurricane lamp can consume about 0.3 litre of kerosene. Hence for an entire year, two kerosene hurricane lamps will consume 219 litres [4][80].

A PV lighting system was compared to a conventional kerosene hurricane lighting system on the basis of their annual cost over a 25 year period. The PV system was sized to provide equivalent or superior performance to the conventional system.

The annual cost of providing a specific energy service was considered the best measure of comparing PV with conventional technologies because of the significant differences in initial cost and annual operating cost between the two types of technologies. The annual cost used for comparison was the annualised present worth of all costs associated with the technology over a life cycle of 25 years. The annualised present worth is the value in 1992 US dollar ($) of equal payments over the 25 year period that add up to the total present worth of all costs associated with the technology.

From the economic analysis above, it is clear that the PV lighting system is more economical than kerosene hurricane lighting on a least life cycle cost basis. Unfortunately many householders are unable to allocate their current income to install a PV system, in the absence of incentives, even if they could realize significant savings over the life span of the system. Their main concern is with the initial capital cost, so it may be necessary to organise a financial package which allows a householder to purchase a PV system and spread the repayment [23]. PV systems are characterized by relatively large purchase/capital costs, low operating and maintenance with no fuel costs. Thus, potential users should always compare the annualised present worth of all costs associated with the different technologies.

Apart from PV lighting systems being cheaper on a life cycle cost basis, they provide considerably more and better quality light than kerosene hurricane lamps. PV is more environmentally friendly and less hazardous. Since most manufacturers do adhere to the international standards on the manufacture of PV systems, it has been realised that the reliability of PV systems is very high [73]. It should be noted that kerosene hurricane lamp manufacturers do not guarantee the reliability of their products.

5.3 PV WATER PUMPING APPLICATION FOR THE GAMBIA.

Solar pumps are used for pumping water from boreholes, open wells, rivers, canals, etc. The provision of clean drinking water is the most important application for PV pumps. Impure drinking water is responsible for a large fraction of the illness and infant mortality in many developing countries. The provision of adequate supplies of clean drinking water is a major social benefit.

Another major importance of solar water pumps is for irrigation of crops. The Gambia, being part of the Sahelian drought-stricken region, has experienced a drop in crop yield mainly because of reduced availability of water for crops. In most cases, PV pumps are provided to villages or communities for drinking and domestic uses. Individual farmers could be encouraged to purchase these systems for irrigation via an attractive financial route for repayment.

In water pumping systems, the use of batteries and voltage regulators can be eliminated by carefully choosing the components of the system. Direct coupling between the PV modules and the motor pump arrangement makes the system simple and autonomous. Repairs and maintenance are reduced to a minimum. Moreover, the system starts to pump in the morning and stops in the evening without any external intervention and can operate with a good adaptation to the available solar power. With these features, the direct-coupled system becomes appropriate for remote areas in the Gambia.

5.3.1 PV WATER PUMPING SYSTEM CONSIDERATION.

In order to design and cost a PV water pumping system, there are a number of factors to take into consideration. Some of these considerations are given below:-

5.3.1.1 Performance of PV Water Pumping System.

Directly connected PV water pumping systems operate under variable conditions of energy supply. The solar irradiance sets the operating point of the directly connected motor-pump system along its output characteristic curve. Its effect on a system working against a constant static manometric head is to indece a wide range of flow velocities and associated velocity - head losses, leading to a variable total manometric head. Figure 5.1 represents a schematic diagram of a PV pumping system.

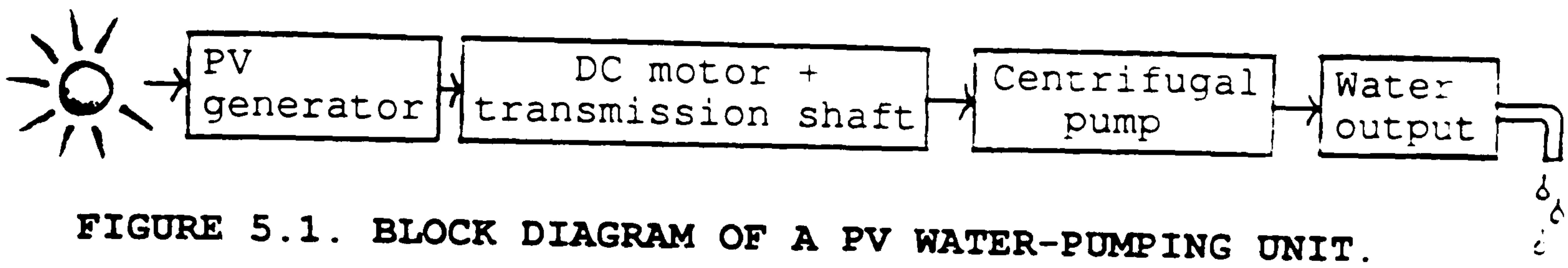


FIGURE 5.1. BLOCK DIAGRAM OF A PV WATER-PUMPING UNIT.

A PV water pumping system could be divided into the following main parts:- PV array, motor, pump and water outlet. The basic processes occurring in the system are as follows:-

(1) solar irradiance is converted into electrical energy by means of the PV array,

(2) electrical energy is converted into mechanical energy by means of the motor,

(3) the mechanical energy is converted by the pump into hydraulic energy and finally,

(4) the hydraulic energy pumps the water - output.

The operating characteristic of a 90V motor-pump system at constant static head is shown in figure 5.2. This characteristic is overlaid with the I-V characteristic of the PV array to determine the operating point.

As the irradiance increases to 12.5Wm^{-2}, the current increases toward point T, which represents the resistance of the armature and brushes. When the current reaches

1.2A and voltage about 6V, the starting torque of 0.28Nm is achieved and the motor starts to turn.

Rotation of the rotor generates a back electromotive force which quickly increases the array voltage. The motor speed, voltage and current all increase with increased irradiance to point P when the pump starts to move water (650 rev/min, 40V & 2A). As the irradiance increases the operating curve passes through the maximum-power point of the array.

The most important consideration in system design is the match between the motor-pump system and the solar array. The optimum operating point of the motor under load would correspond to the locus of maximum-power points of the array over the majority of the motor speed range. Also important is the selection of the pump to match the conditions of variable motor speed, required head and maximum flow. Figure 5.3 shows the variation in flow rate against irradiance.

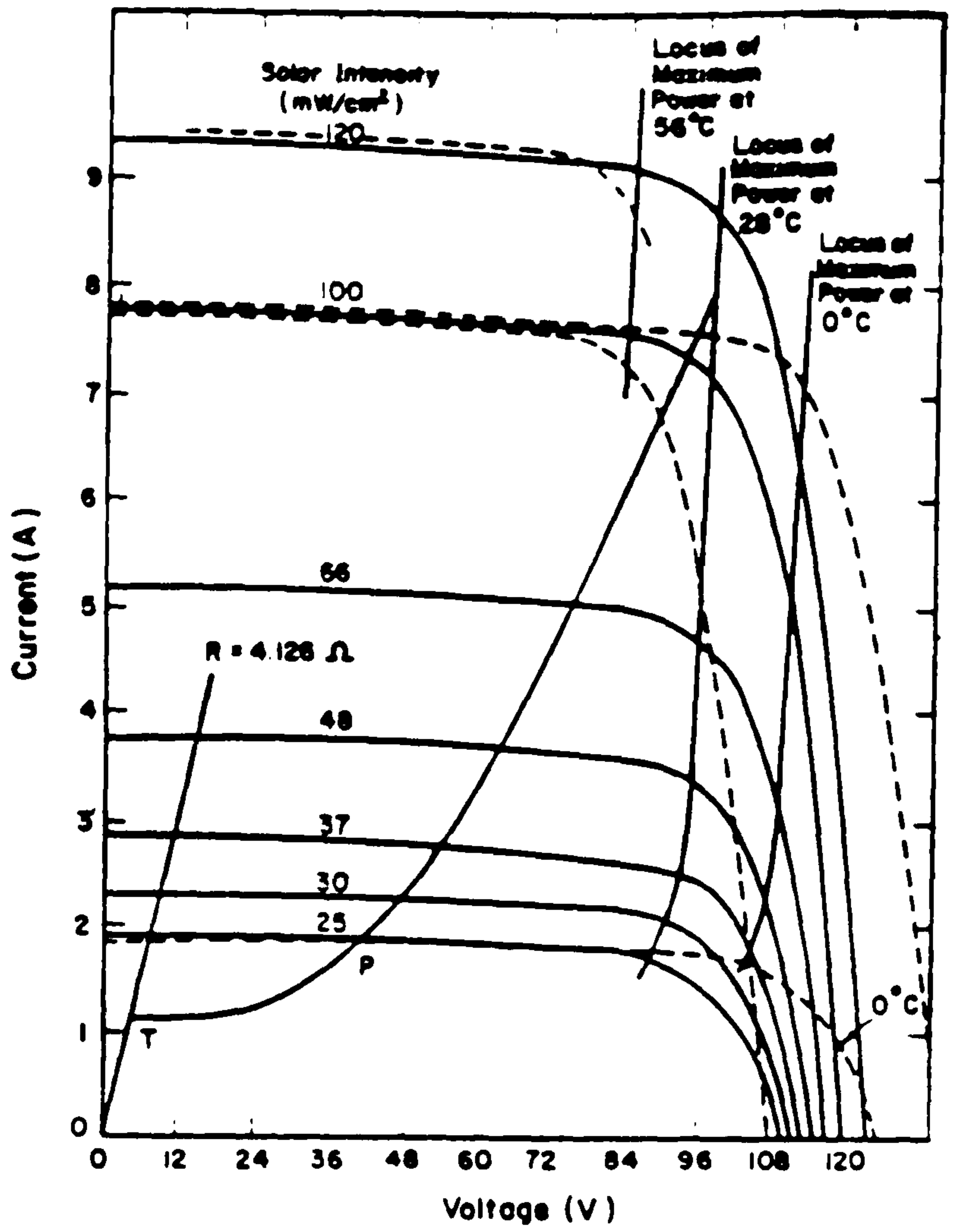


Figure 5.2 Operating characteristics of a 90V motor with a solar array [73].

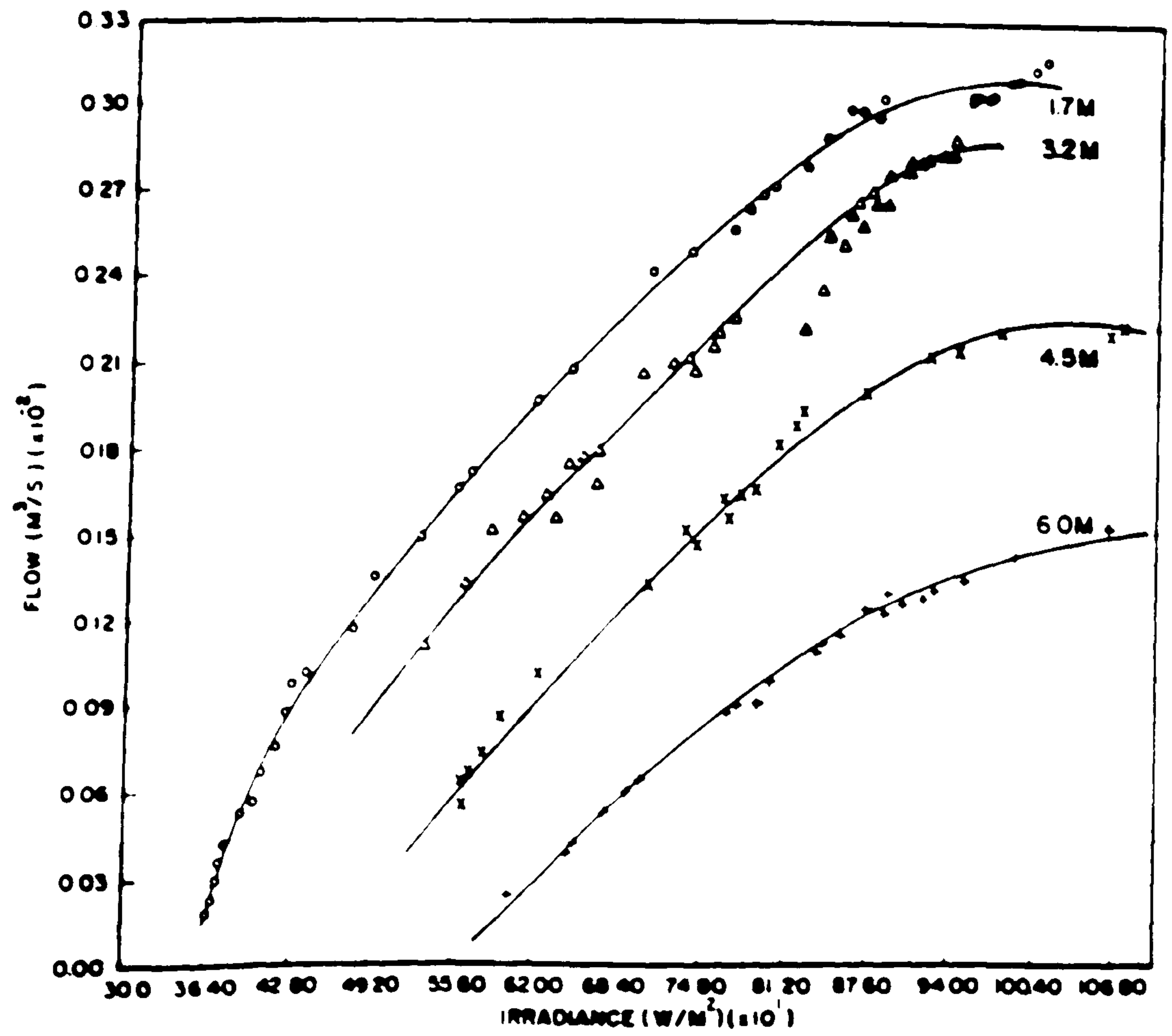


Figure 5.3 Change in flow rate with irradiance at constant heads [73].

5.3.1.2 Cost Appraisal of Water Pumping System.

The cost appraisal involves the following procedures:-

(1) Calculating the hydraulic energy requirements for the month with greatest water demand.

(2) Determining the design month.

(3) Sizing the PV array, motor and pump source.

(4) Determining the installed capital cost of the whole system.

(5) Determining the present worth of the recurrent costs, sub-divided into:- (a) replacement costs (b) maintenance costs and (c) operating costs.

(6) Calculating the life cycle costs.

(7) Calculating the unit water cost.

5.3.1.3 The Hydraulic Energy Requirement for the Design Month of the Year.

The main uses of water in the Gambia are for agricultural and domestic purposes. The hydraulic energy needed could be determined by first assessing the total gross water requirement for each month. The hydraulic energy required to deliver a volume of water is given by the formula:- $E = hpgV$.

where E is the required hydraulic energy in Joules.

V is the required volume of water in cubic metres(m^3).

h is the total head in metres(m).

p is the density of water($1000 Kg/m^3$).

g is the gravitational acceleration($9.81 m/s^2$).

The hydraulic power (Watts) is given by:- $P = hpgQ$.

where Q is the water flow rate.

Hydraulic energy = $9.81(m/s^2)$ * volume(m^3/day) * 1000(kg/m^3) * total head(m).

The total head comprises the sum of the static lift (including that due to the delivery and storage system) and the head loss in any pipes, which depends on the pipe diameter and the flow rate. The head losses are usually taken as 10% of the total static head (in metres). In our calculations the static head is taken to be constant throughout the year. However, where there are variations due to drawdown, monthly mean values of the static head should be used.

In the Gambia, the month of May is the period for which water demand is greatest since it is towards the end of the dry season. The typically village of Lamin with about 1,000 inhabitants will require about $40m^3$ per day [75]. The total system head is taken as 12 metres.

The hydraulic energy requirement for Lamin village = $9.81 * 40 * 1000 * 12 = 4.71$ MJ/day ≡ 1.31 KWh/day.

5.3.1.4 The Design Month.

The PV pumping system for Lamin village is to be designed as a stand alone system to provide all the water requirements for the village. The design month is the month in which the water demand is highest in relation to the solar energy availability. The highest ratio of the hydraulic energy requirement to the solar energy available for each month is 1.31/4.5 m^2. The design month is August having the lowest insolation of 4.5$KWhm^{-2}$/day.

5.3.1.5 The PV Array, Motor and Pump Sizes.

The electrical energy required from the PV array is equal to the required hydraulic energy divided by the average sub-system daily energy efficiency. From figure 5.4, the required PV array size could be obtained from the hydraulic energy load for the design month. For a daily energy demand of 1.31KWh with a sub-system average daily energy efficiency of 50% and an average minimum radiation of 3.5KWh/m^2, the required PV array rating is found to be 875Wp.

The motor must be able to withstand the peak output of the array of 875W. The configuration of the PV array can usually be arranged to match the current and voltage limitations of the motor, provided that the maximum power ratings are adequate.

The pump is required to produce about 40m^3 of water each day for the villagers in Lamin. The pump size must be chosen such that the hydraulic power output is equal to or greater than the product of the array power and the sub-system power efficiency. The water requirement for the village is an average figure taking into consideration the availability of a storage facility.

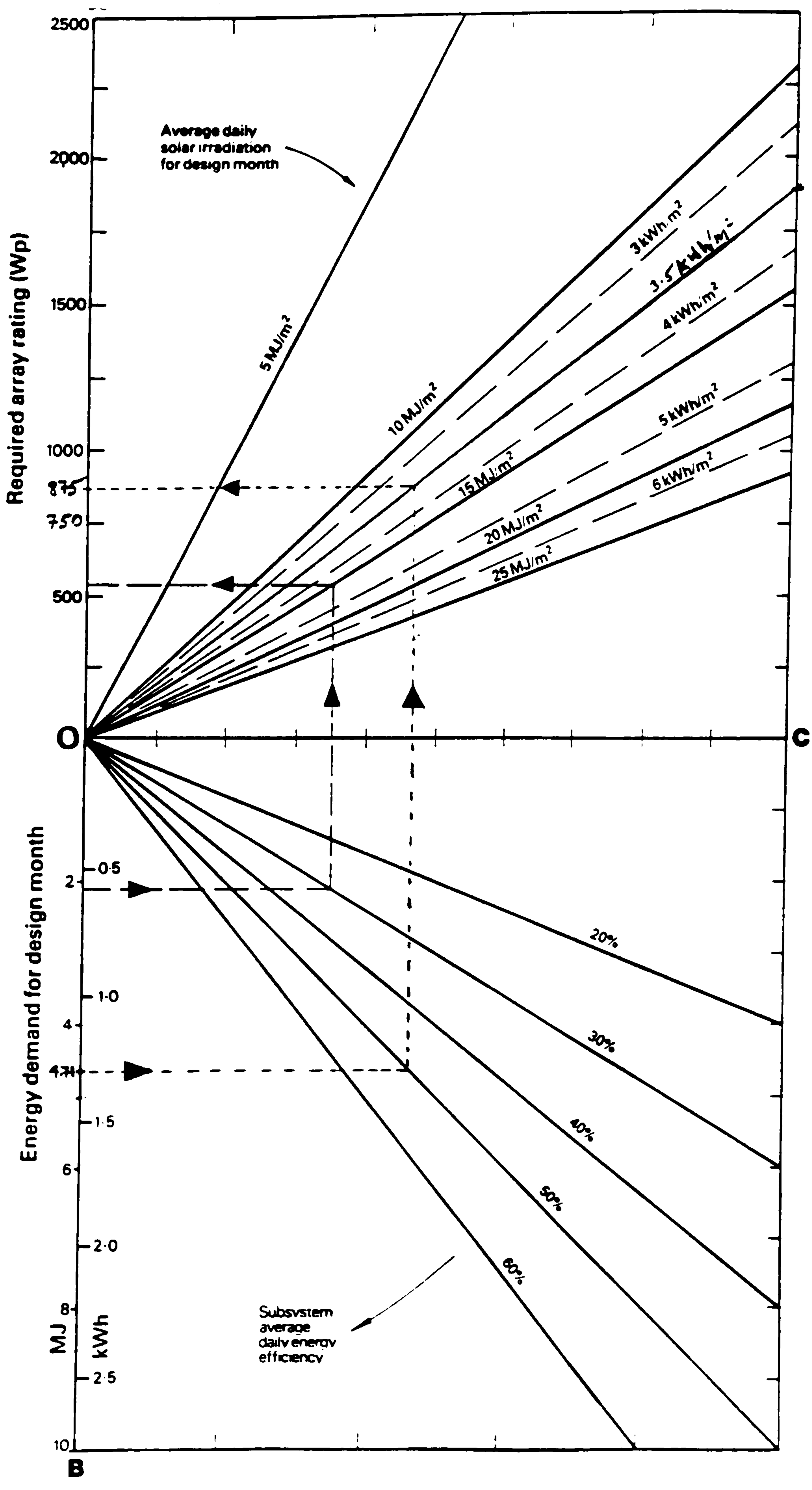


Figure 5.4 Nomogram for system sizing [81].

5.3.1.6 Costings of the PV Pumping System.

The total cost of the system will be comprised of:-

(1) Modules

(2) Motor & pump

(3) Pipework

(4) Wiring

(5) Control system

(6) Transportation & installation

(7) PV array support structure

(8) Civil works in digging of well

(9) Storage tank

(10) Labour

5.3.1.7 Alternative Pumping System - Handpumps.

In the Gambia over 75% of pumps used in communities with a water supply system are handpumps. More than one handpump would be used in medium size villages (200 - 500 persons). In some cases where demand is outstripping the capacity of handpumps, they are being replaced by PV pumps. Studies in other countries have shown that the economics of PV pumping relative to handpumps vary depending on water requirements and the pumping head [77].

5.3.1.8 Costing of the Handpumping System.

The cost of the total system will comprise the following:-

(1) Handpump, (2) Pipework, (3) Transportation & Installation and (4) Civil works in digging.

TABLE 5.3 COSTS OF PV PUMP VERSUS HANDPUMP SYSTEM[79][82].

	Handpump($)	PV Pump($)
Array & pump system cost (875Wp @ $9/Wp).		7,875.00
Transportation, installation & civil works.	2,595.00	3,500.00
Storage tank.	None	500.00
PW of replacement costs(spares).	635.50	8905.00
PW of maintenance costs.	227.30	3,185.00
PW of labour cost.	20,383.80	20,383.80
Handpump system.	255.80	
PW of handpump (life = 5yrs.)	1,084.59	
Total Life Cycle Cost (LCC)	25,181.99	44,348.80
Annualised LCC (LCC/25yrs)	1,007.28	1,773.95
Unit Water Cost (ALCC/365 days/m^3)	0.14	0.12
Daily Quantity	($20m^3$)	($40m^3$)

5.3.2. ECONOMIC VIABILITY OF PV PUMPING SYSTEM VERSUS CONVENTIONAL HANDPUMPING SYSTEM.

From the economic analysis on table 5.3, the ALCC of the PV and handpumps are $1,773.95 and $1,007.28 respectively. These costs were obtained for a life cycle of 25 years each. The unit water cost (UWC) of the PV and hand pumps are $0.12 and $0.14 per m^3. For larger water requirements, PV pumps operate at a lower UWC, and for lower demand, handpumps are more cost effective [73].

The two main disadvantages of the handpump are the waiting or queuing time because of the slow rate of water discharge and the physical strength needed to operate the pump, such that only adults can operate the handpump system. For a larger population, several handpumps would have to be installed to be equivalent to the water output per day of a PV pump.

A PV system does not face a queuing limitation since a storage tank is included in the system. This makes it possible for water to be available at all times with increased reliability. Even with the high cost of storage in the PV systems, the relatively large population served compared to handpumps helps to bring down the UWC.

5.4 PV MEDICAL APPLICATION FOR THE GAMBIA.

The provision of health care in rural and some urban areas is a major task in most developing countries and is seriously hindered by the absence of energy supplies. One of the major preventive health programmes being undertaken by nations around the world in collaboration with the World Health Organisation (WHO) is the Expanded Programme on Immunization (EPI). EPI is only one of a number of components of primary health care, yet few children or pregnant women in the developing world are now being immunized. As a consequence there are up to 5 million needless deaths per year due to immunizable diseases, with a similar number of needless crippled or mentally retarded children [83]. One of the goals of the EPI is to make routine immunization services available to every pregnant mother and child under the age of one year in the world [84]. However, in order to realize its goal, the EPI must ensure that a reliable and permanent "cold chain" is firmly established.

In the Gambia, the medical and health department runs an immunisation programme with assistance from the WHO. The success of this immunisation programme depends on the maintenance of the cold chain for vaccines, which must be kept at temperatures between 0 and $8^{o}C$ from manufacture to injection if they are to be effective. PV powered refrigerators are used. Emergency standby batteries in hospital operating theatres are continuously being charged by PV systems and some sterilising units are also PV powered.

5.4.1 PV REFRIGERATOR VERSUS KEROSENE REFRIGERATOR FOR VACCINES.

There are several rural and urban areas where fuel supplies are non-existent or erratic. This has resulted in the provision of over 50 PV refrigerators for the Gambia by WHO, in order to keep the vaccine "cold chain" in proper operation. All gas and kerosene refrigerators used throughout the 54 health centres countrywide were replaced by solar refrigerators [85].

The performance of refrigerators fuelled by kerosene is often inadequate hence resulting in vaccines being ineffective or spoiled. The use of more reliable PV refrigerators increases the number of doses of vaccine successfully delivered in an immunization programme, thus making better use of the overall immunization programme overhead costs. This can be quantified [75] and has been used in assessing PV prospects for health care applications [86][87]. Solar power is therefore of great importance to health care. During the fuel shortage period of 1990, all the kerosene operated vaccine refrigerators went out of action, resulting in a halt in the immunization services of the Gambia.

The first PV refrigerators were installed in 1981 and even these early trials showed that vaccines were maintained within the temperature limits for over 80% of the time, as opposed to about 60% for kerosene powered units [88]. Provided that the systems are correctly designed and installed and that users are trained, solar refrigerator systems have a high reliability during the first 4-5 years after installation. Performance is much better than that of kerosene systems. The average mean time between failure (MTBF) was found to be 4 years with an availability of 90% [85].

Absorption refrigerators are the only cooling systems that can run on kerosene but they are not reliable. They have no thermostat and therefore cannot adequately control the internal temperature for vaccines. Sometimes the quality of the kerosene in rural areas is too poor to operate the system properly [89].

A significant breakdown in the PV refrigerator system is caused by failures of the battery/charge regulator pair which has proved to be the weak link of the system. Some causes of failure are given below:-

(1) Use of poor quality batteries not designed for a refrigerator load, such as standby batteries rather than deep cycle/heavy duty batteries.

(2) Inadequate sizing of the solar generator (array and batteries) for the site of installation.

(3) Inadequate matching of the generator to the charge specification of the battery bank.

With proper management of the system, the PV technology would be proven reliable and provides a very good temperature control of the vaccines.

5.4.1.1 Performance of PV Vaccine Refrigerator.

Vaccine refrigerators are required to maintain vaccine between $0^{o}C$ and $8^{o}C$ at all times. The performance of a refrigerator or freezer is dependent on the ambient temperature, therefore specifications are usually defined at $32^{o}C$ and/or $43^{o}C$. The following criteria are used to assess performance:-

(1) Internal temperature distribution and variation within the permissible range of $0^{o}C$ to $8^{o}C$.

(2) Holdover time between loss of power. This is the length of time for which the internal temperature of the refrigerator will remain below $8^{o}C$ when the power supply has been disconnected.

Figures 5.5 and 5.6 represent the temperature evolution of 34kg of water in a PV vaccine refrigerator. It can be observed from the performance graphs that it takes about 32 hours to cool the 34kg of water from an initial temperature of $28^{o}C$ to $4^{o}C$ with an average ambient temperature of about $32^{o}C$. This is defined as the "cool-down" time of the refrigerator enclosure. The refrigerator enclosure can maintain the temperature of the 34Kg of water, initially at $0^{o}C$, at below $8^{o}C$ for about 25 hours. This is defined as the "hold-over" time of the refrigerator enclosure.

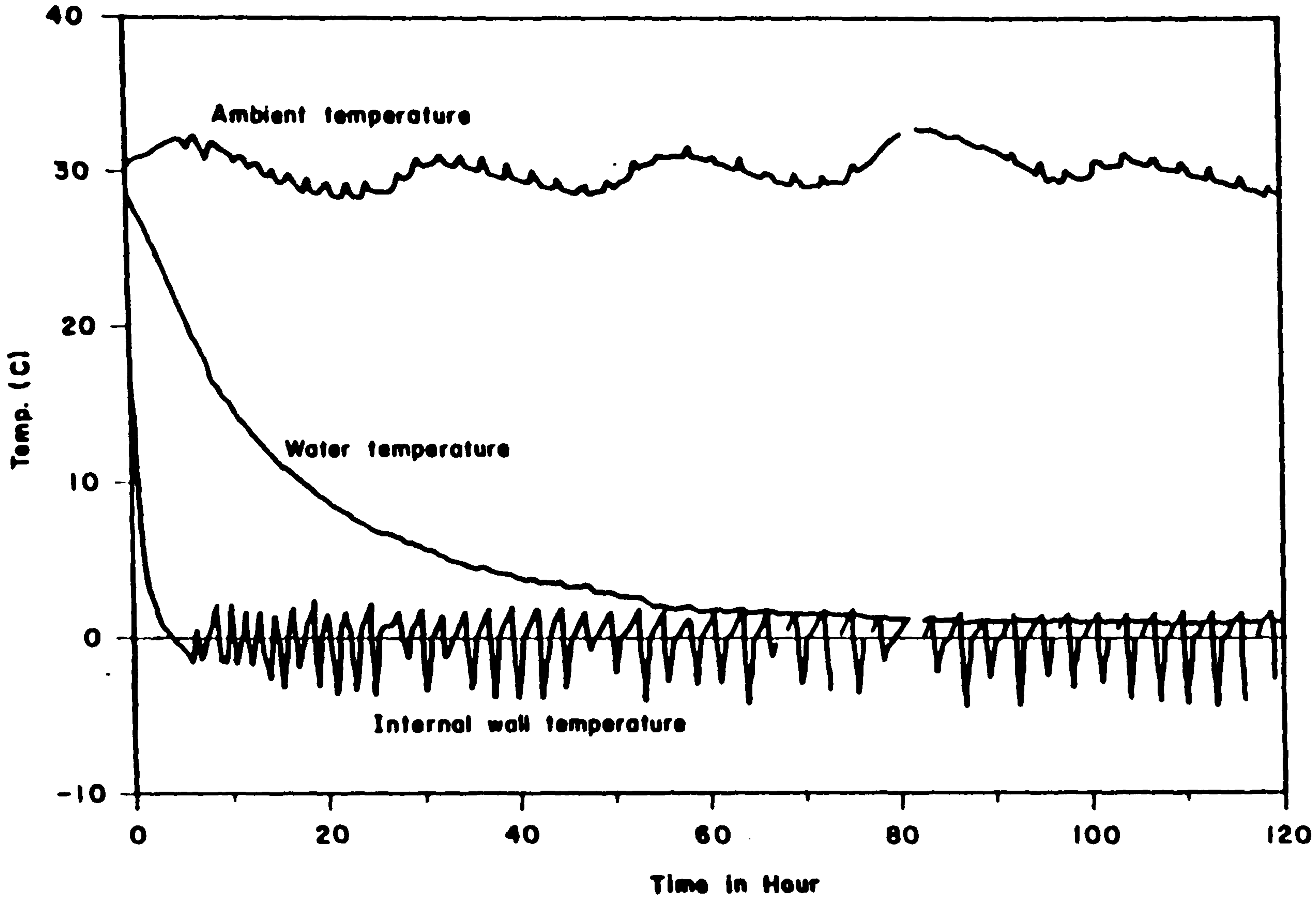


Figure 5.5 Temperature evolution in the cooling of 34kg of water [73].

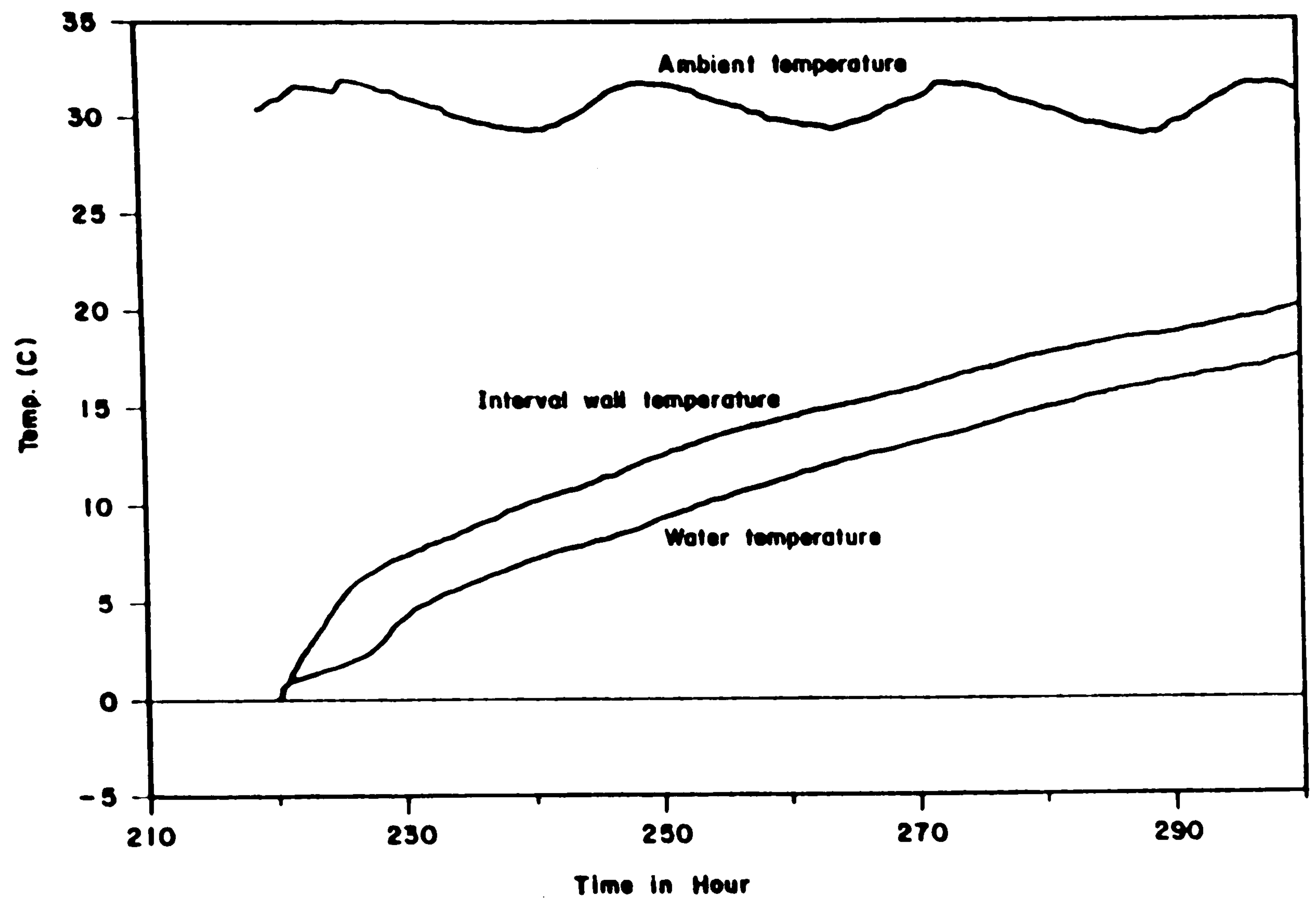


Figure 5.6 Temperature evolution of 34kg of water when the compressor is turned off at 217.7 hours [73].

5.4.1.2 Design of PV System for Vaccine Refrigerator.

The energy consumption of a PV vaccine refrigerator is typically 300 to 500 Watt hours per 24 hours for a 100 litre refrigerator at $+32^{o}C$ ambient temperature [81]. A capacity to run the refrigerator for 5 days without sun is usually recommended [90].

For a maximum power consumption of 500 Watts hours and a 5 day no sun period the total power needed is:-
500Wh * 5 = 2,500Wh.

Since there is power loss in the battery storage system during charging and discharging, the power requirement is scaled up to 2,500/90%*90% = 3,087Wh.

The number of (L120 12V 120Ah Solarbloc L) batteries needed [23], with 80% depth of discharge, is 3087Wh/12V*120Ah*80% = 3.

With an average daily solar insolation of $5.5KWh/m^2$ in the Gambia, 6 @ 95W (BP495) high power modules will produce a daily output power of (6*95)*5.5 = 3,135Wh.

5.4.1.3 Medical Refrigerator - PV versus Kerosene.

The PV refrigerator has the following advantages over the kerosene refrigerator:-

1 - Improved vaccine storage facilities due to:-

(a) elimination of fuel quality problems,

(b) greater refrigerator reliability and

(c) better refrigerator performance with temperature control.

2 - Reduced running cost as a result of:-

(a) elimination of kerosene fuel costs,

(b) elimination of kerosene transportation costs,

(c) reduced vaccine losses,

(d) lower refrigerator maintenance costs and

(e) reduced need for back-up refrigerators where there are fuel supply or repair problems.

3 - Cold chain management benefits due to:-

(a) longer equipment life and

(b) reduced logistical problems arising from non-availability of working refrigerators and associated vaccine losses.

The above operational advantages of introducing solar refrigerators into the cold chain indicate that solar refrigerators can provide a more sustainable vaccine cold chain. The main disadvantages of PV refrigerator are as follows:-

(1) more time necessary for planning and implementing a PV project since it is site specific and

(2) user training demands are higher since over loading a solar refrigerator can cause the refrigerator to become too warm.

TABLE 5.4 COST OF PV REFRIGERATOR VERSUS KEROSENE REFRIGERATOR FOR VACCINE STORAGE IN THE GAMBIA.

	Kerosene($)	PV($) [79]
Array (6*95W-BP495) @£735 each-25yrs.life.		6,204.86
Battery (3*$111 each) 5yrs.life.		333.00
Medical refrigerator (BP VR50).	1,110.00	2,024.00
Installation costs.	112.50	205.00
Total installed costs	1,222.50	8,766.86
Annual maintenance cost (M.C.).	142.50	37.50
Annual fuel costs (57¢ per litre, 274 litres per year) (F.C.).	156.18	
PW of batteries (life=5yrs.)		1,411.92
PW of recurring costs maintenance (26.5*M.C.).	3,776.25	993.75
PW of refrigerator (life=10yrs).	2,375.40	4,331.36
PW of recurring costs fuel (26.5*F.C.).	4,138.77	
Total life cycle cost (LCC).	11,512.92	15,503.89
Annualised refrigerator LCC(ALCC).	460.52	620.16
Refrigerator reliability/availability.	60%	97%
Out of 10,000 doses per year, the potent vaccine dose available.	6,000	9,700
ALCC per potent vaccine dose.	$0.08	$0.06

5.4.2 COMPARATIVE COSTS - PV VERSUS KEROSENE REFRIGERATORS.

A PV refrigerator costs more than that powered by kerosene and installation costs are also higher for PV. However, a kerosene refrigerator will use about 0.5 to 1 litre of fuel each day, require frequent maintenance and have a shorter life. Table 5.4 gives the life cycle cost analysis of utilizing a PV or kerosene refrigerator in a health centre in the Gambia.

From Table 5.4, it can be noted that the life cycle cost of PV is higher than that of kerosene but because of PV's greater reliability and resultant savings in wasted vaccine, it is more cost-effective on potent vaccine dose. Hence PV is preferred to kerosene [56][81].

5.5 CONCLUSION.

The economic, technical and reliability analysis of a PV lighting system compared to a conventional kerosene hurricane lighting system does give a clear indication that the PV system is of a superior standard. Its benefits are overwhelming. Unfortunately, individuals do not evaluate products on this basis, with their main concern being on initial capital cost even though they will have to pay lot more on a life cycle cost basis. The feasibility, viability and prospects of this PV system are quite good for the Gambian situation.

The economic viability of PV water pumping compared to the conventional hand-pumping mainly depends on the quantity of water needed and the head size. It has been observed that it is more economical to use handpumps for lower quantity and head size, but, for larger water quantity or head size, PV pumps are more favourable. There is a cross-over point, where both systems are equally favourable and this point varies with variation in economic or technical parameters.

Although a kerosene refrigerator has a lower annualised life cycle cost than that of a PV refrigerator, the reliability and availability factor of PV is higher hence making the annualised life cycle cost per potent vaccine dose lower. If the reliability/availability factor of the kerosene refrigerator was to increase by another 15%, then it would be more cost effective than a PV refrigerator.

CHAPTER 6

6.0 PV FOR HIGHVALUE ADDED ACTIVITY.

This chapter provides an economic case study of photovoltaics (PV), diesel and PV/diesel hybrid systems for powering telecommunications and navigational aids at Banjul International Airport in the Gambia. Like many developing countries, the Gambia has significant solar energy resources, making the use of PV appear favourable in many cases. Since all oil products and spare parts are imported, a conventional diesel generator has a significant cost, particularly in terms of foreign exchange.

Development efforts are greatly enhanced by improvements in telecommunication systems within the country and with the outside world. In the Gambia, most of the telephone networks in the rural areas are PV powered. They require little power, but reliability is of paramount importance. Some other telecommunication uses include TV, the recharging of batteries for radios, radio transceivers for aid workers, health centres and navigational aids.

The Gambia Civil Aviation Authority (GCAA) have navigational aids and communications equipment at remote sites. The cost of maintaining these diesel generators is proving to be extremely high [23]. Standby batteries are currently being used for all these types of equipment, making the situation favourable for the use of PV power with increased confidence and reliability.

The equipment under consideration is presently powered by a diesel generating system and comparison will be made between the present system and an alternative PV generation system. Operational experience would suggest that a PV/diesel hybrid system may be the optimum solution at present. This chapter will also discuss the technical and economic analysis necessary to determine the specifications of an optimal hybrid system and provide an economic assessment of the diesel, PV and PV/diesel options on a least cost life cycle basis.

6.1 PV AND DIESEL POWERED COMMUNICATIONS SYSTEM CONSIDERATION.

Below is given the performance, sizing and economic considerations for both PV and diesel powered communications systems.

6.1.1 PERFORMANCE AND SIZING CONSIDERATIONS.

PV powered telecommunications systems have several advantages over conventional systems. They include:-

(i) having a highly reliable power source,

(ii) being sized to provide the relatively small amounts of power required for transmission and receipt of signals and

(iii) being able to operate for long periods unattended, needing little or no maintenance.

The total power profile and energy over some increment of time is essential for the sizing of the PV array and battery. For system sizing purposes, a worst case load profile for the worst time period of the year is usually necessary - i.e. the highest ratio of energy demand to solar energy availability.

It is vital that three important factors of the telecommunications system are known:-

(i) The continuous standby power for the equipment.

(ii) The transmitting and receiving power.

(iii) The time period (hours) that the equipment will be transmitting and/or receiving.

6.1.2 ECONOMIC COMPARISONS OF PV AND DIESEL POWERED COMMUNICATIONS SYSTEMS.

The communications system assumed here is DC powered. The load (communication system) is also assumed to be identical for both the PV and the conventional system. Therefore the financial comparison is performed only between power systems, excluding any load costs. The maximum daily DC power requirement of the system is represented by 'x'.

The conventional power system is a tandem diesel generator system operated on alternate days. It is assumed that the supply of diesel fuel, spare parts and maintenance for both systems are never interrupted and their availability is 100%.

6.1.3 PV POWERED COMMUNICATIONS SYSTEM DESCRIPTION AND COSTS.

The components and costs of the PV powered system for communications application are given below:-

(i) PV array sized to supply daily power of 'x' with a battery storage size for 3 days during the lowest-month daily irradiation.

(ii) Cost of array system = \$ AS   (All in US \$)

(iii) Cost of battery system = \$ BS

(iv) Charge controller system to operate satisfactorily with PV and battery system.

(v) Cost of charge controller = \$ CC

(vi) Annual maintenance/manpower cost = \$ AM.

The initial capital cost for the PV-powered system has three components: the array (\$ AS), batteries (\$ BS) and charge controller (\$ CC). Recurring costs are those associated with component replacement, maintenance and repairs.

PV module and related balance of system costs are estimated at about $\$8Wp^{-1}$ [73]. Sealed deep discharge batteries are normally used for communications. The cost for these batteries is approximately $\$150KWh^{-1}$ and the cost of the electronics is approximately $\$0.40W^{-1}$. The batteries are assumed to need replacement every 5 years and the control electronics every 10 years. The annual maintenance and repair cost is usually taken as 0.05% of the total system capital cost [73].

6.1.4 DIESEL POWERED COMMUNICATIONS SYSTEM DESCRIPTION AND COSTS.

The components and costs of the diesel powered system for communications application are given below:-

(i) Two diesel generators, each providing an output power which is enough to operate the communications system through an inverter system.

(ii) Cost of each generator = $ GE

(iii) Cost of AC-DC inverter = $ IN

(iv) Cost of annual fuel = $ AF

(v) Cost of annual replacement parts = $ RP

(vi) Cost of annual maintenance/manpower = $ AM

The capital cost of the diesel powered system is based on the use of two diesel generators (2 x $ GE). The engines need replacement every 6 years. Fuel consumption rates vary as a function of the size of the engine, the engine efficiency, the number of hours that the engine runs and the load factor at which the engine operates. Engine overhauls are assumed to require an expenditure equivalent to 15% of the engine's capital cost every 3 years. Annual maintenance/repair costs are assumed to be equivalent to 2% of the capital cost of the system [72].

6.2 ECONOMIC COMPARISONS OF PV AND DIESEL SYSTEMS FOR TELECOMMUNICATIONS AT BANJUL INTERNATIONAL AIRPORT.

Banjul International Airport (BIA) is situated in Yundum, about 45km from Banjul, the capital of the Gambia, and the telecommunications (telecomms.) and navigational aids (navaids) are situated at Koloro, a further 30km from the airport. The equipment to be powered includes Doppler VHF Omni Range (DVOR), Distance Measuring Equipment (DME), Outer Marker (OM), UHF Communications Link (UCL), two air-conditioners (ACON), operating on alternate basis, and five 40W fluorescent lights. This equipment is presently powered, on an alternating basis, by one of two 58.8KVA diesel generators on the site. The equipment (except the air-conditioners) operates on DC electricity with battery back-up. The AC power from the generators must be converted to DC for both operating the equipment and battery charging, with the attendant power losses.

The DVOR, DME and OM are used by aircraft for angle, distance and position information respectively. The UCL is used as an intercommunication system between the navaids site at Koloro and the airport.

The cost of maintaining these diesel generators is proving to be extremely high. This chapter presents the operating and maintenance costs of the diesel generators and then analyses the present worth of the system over a 25 year life span period. Tests have shown that the efficiency of diesel generators is dependent on the load factor and the period from start-up to shut-down [91]. Diesel engines are commonly used for providing power in rural areas in The Gambia, especially where there is no electric grid. Logistical support constraints have highlighted the need to consider appropriate renewable energy sources like PV. Economic assessment of the operational and maintenance costs could reveal the attractiveness of PV or PV/diesel hybrid systems.

PV could provide significant energy for development particularly if the technology is judged on a least cost life cycle basis. Six years ago, the Newcastle

Photovoltaics Applications Centre proposed a model on the market readiness of PV systems. It argued at the time that small power demands for high value applications, such as telecomms. and navaids, was rapidly becoming a mature market [92][93]. In many applications PV is competing against diesel generators. Diesel generators are commonly used to provide power in rural areas of the developing world, where there is no electric grid. Efforts to establish PV in this enormous market have been slowed because of a lack of reliable data on the cost of operating a diesel generator. The difference in the Present Worth (PW) of each system will determine whether or not PV is an economical alternative. Without these analyses, it is difficult to show that PV is less expensive in the longer term. As a result, a potential buyer will often choose a diesel because it is a known technology and has lower initial costs. This chapter provides a case study from the Gambia, comparing PV and diesel systems for the provision of power to telecomms. and navaids at BIA.

At present, almost all electricity generation in the Gambia is from oil products which must be imported in their refined state. This importation is a direct drain on foreign exchange, in terms of both capital requirements and recurrent costs [80][94]. This makes the assessment of the economics of PV, and where appropriate hybrid systems extremely important, since all technologies must be financed from scarce foreign exchange. Additionally, there are the environmental effects of the oil based systems which are increasingly a matter of concern for all governments has been discussed in chapter two.

The navaids are used by approaching and en-route aircrafts, and it is desirable that its availability is high (95% or greater). For high system availability, the cost of extra batteries and PV arrays is expected to be significant as availability requirements rise beyond a certain point. One method of mitigating the problem of diminishing return on investment is to supplement intermittent solar energy with fossil fuel to achieve acceptable levels of system availability while limiting total system cost [95][96]. Operational experience would suggest that the model of best practice for medium to high power demand may be a PV/diesel hybrid system. This method favours high system availability, low fuel use, infrequent maintenance, and sufficient fuel storage to ensure that refuelling is only required during planned maintenance visits.

6.2.1 METHODOLOGY OF COSTINGS.

The costs involved in the operation of the present diesel system can be divided into four categories:-

(a) Purchase cost in foreign currency.

(b) Installation cost in local currency.

(c) Operation and maintenance costs in local currency.

(d) Foreign exchange costs for purchase and operation for the required life span. All items needed to maintain efficient operation must be imported at present.

The costing of the PV system considers a worst case insolation period of 4.5 sunhours, with adequate battery storage for the maximum cloud period of 3 days prevailing in the Gambia. The analysis also takes into account the reduction in operation and maintenance costs, including the reduced requirement for site visits, for the autonomous PV system. A comparison will be made of the cost performance of the present diesel system with the proposed PV stand-alone system and the PV/diesel hybrid system. The economic appraisal used in assessing the benefits of the different energy systems is the life-cycle cost method [76][81]. The methodology is explained in sub-section 5.1.2 and 5.1.2.1 of the previous chapter.

6.2.2 PV POWERED TELECOMMUNICATION SYSTEM DESCRIPTION AND COSTS.

The components and costs of the proposed PV powered system for telecommunication system at BIA are given below.

6.2.2.1 The PV System.

The Navaids at BIA are used by incoming and en-route aircrafts, and availability is expected to be high especially during poor visibility. Energy source availability of 95% or higher is desirable for an important and popular airport like BIA.

The PV & battery storage system needed to meet such requirements must be sized for a worst case scenario with low probability weather conditions. The annual overall assessment of the system will result in a significantly oversized array and battery storage for the average weather conditions prevailing in The Gambia. In reference [97], it has been shown that the storage system increases by a factor of 10 for an increase in PV system availability of 94% to 99.96%, illustrated in figure 6.1. This is a huge cost to pay for just an increase in availability of 5.96%. As the load requirement becomes greater than 10KWh/day, the cost of oversizing can become substantial, making the system uneconomical for a stand-alone PV option [97].

6.2.2.2 Power Requirement of each Equipment & Costs.

TABLE 6.1 - POWER REQUIREMENT FOR NAVAIDS AT BIA.

Equipment	Voltage & Current Requirement.	Tx. Power Output.	Total DC Power Requirement.
DVOR	24V & 22A	50W	528W
DME	120V & 10A	600W	1200W
OM	24V & 1.5A	1.5W	36W
UCL	24V & 1A	10W	24W
ACON	220V & 14A	---	3400W
5-bulbs	24V & 1.66A	---	200W
Total DC Power Requirement			5388W

Tx = Transmitter.

6.2.2.3 PV Sizing, Installation and Operational Cost.

The sizing and costings of the PV array are done on the assumption that the required power (i.e. current & voltage) can be obtained at the calculated cost.

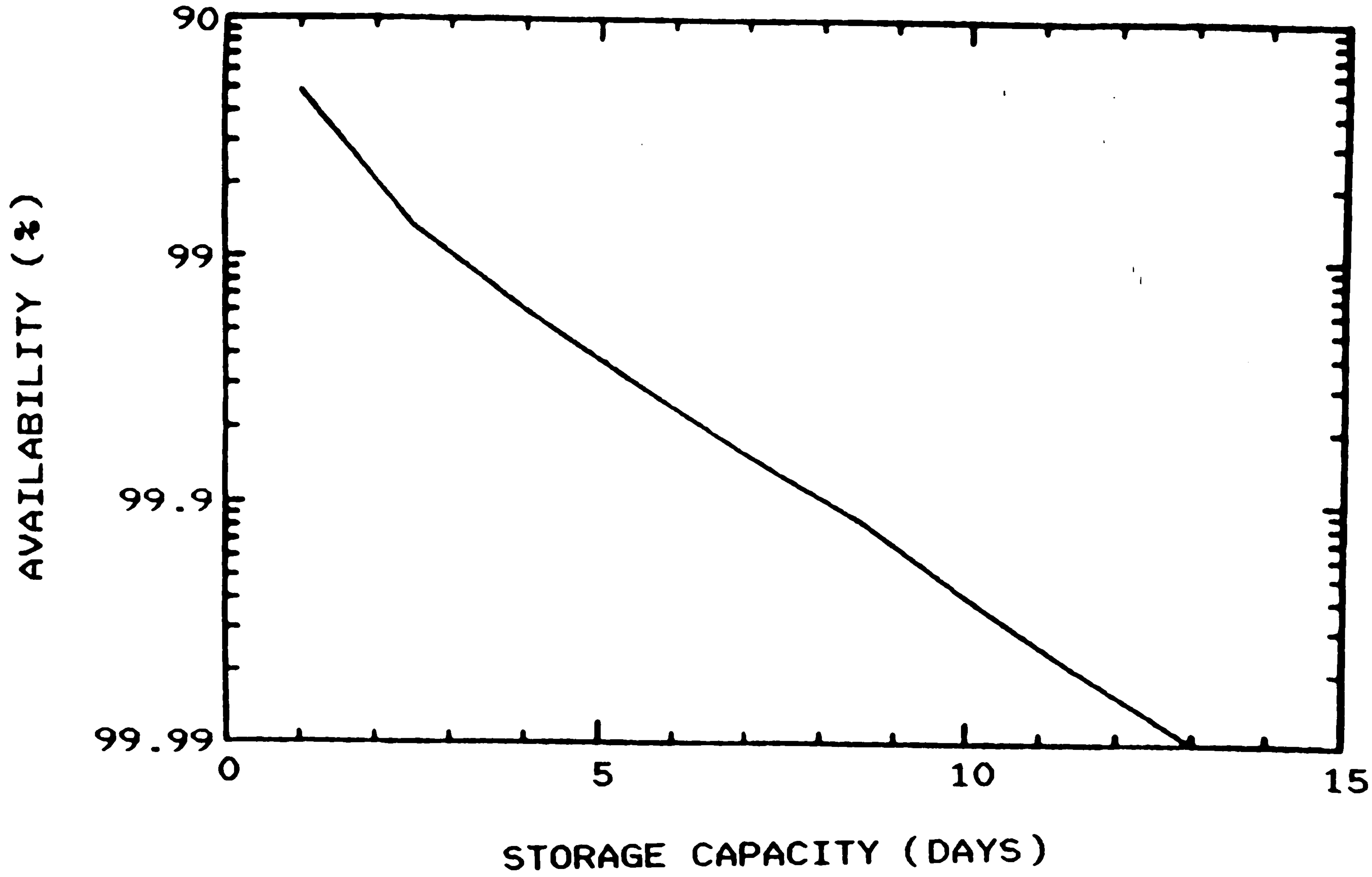


Figure 6.1 Graph of availability versus days of storage capacity for a fixed PV module size [97].

P1 = PV array sized to supply daily power of 5.388KWx24h = 129.312KWh.

P2 = PV array peak power needed with adequate battery storage size for 3 days cloud period during lowest month daily irradiation of 4.5 sunhours = 3 x 129.312KWh/4.5 sunhours = $86.21KW_p$.

P3 = Utilizing deep discharge batteries of 95% & accounting for power loss within the whole electrical network. The total peak power needed from PV array = $86.21KW_p$ x 1.1 = $94.82KW_p$.

P4 = Cost of array system = $94.82KW_p$ x $\$8,000(KW_p)^{-1}$ = $758,560.

P5 = Battery capacity = 129.312KWh x 3 x 1.05 = 407.34KWh

P6 = Cost of battery system = 407.34KWh x $\$150(KWh)^{-1}$ = $61,100.
PW (life=5yrs.) = $258,801.
LCC = $319,901

P7 = Cost of electronic charge controller system and electrical accessories = 407.34KWh x $\$4.00(KWh)^{-1}$ = $1,629.
PW (life=10yrs.) = $3,489.
LCC = $5,118

P8 = *Annual maintenance & manpower cost = 365 x $1.34 = $489.
PW = $12,981.

P9 = *Cost of transportation & installation of PV system = $1,500.

P10 = *Cost of annual site visit/inspection = $360.
PW = $9,554.

P11 = Total Life Cycle Cost (LCC) = $1,107,614.

P12 = Annualised LCC (LCC/25yrs) = $44,305.

* Costings obtained in local currency then converted to US Dollars. The exchange rate of the Gambian currency (Dalasi) to the US Dollar is taken as 9:1, Where US $1.00 ≡ D9 (Dalasi).

The costs involved with the PV stand-alone system is shown in table 6.2 and illustrated in figure 6.2.

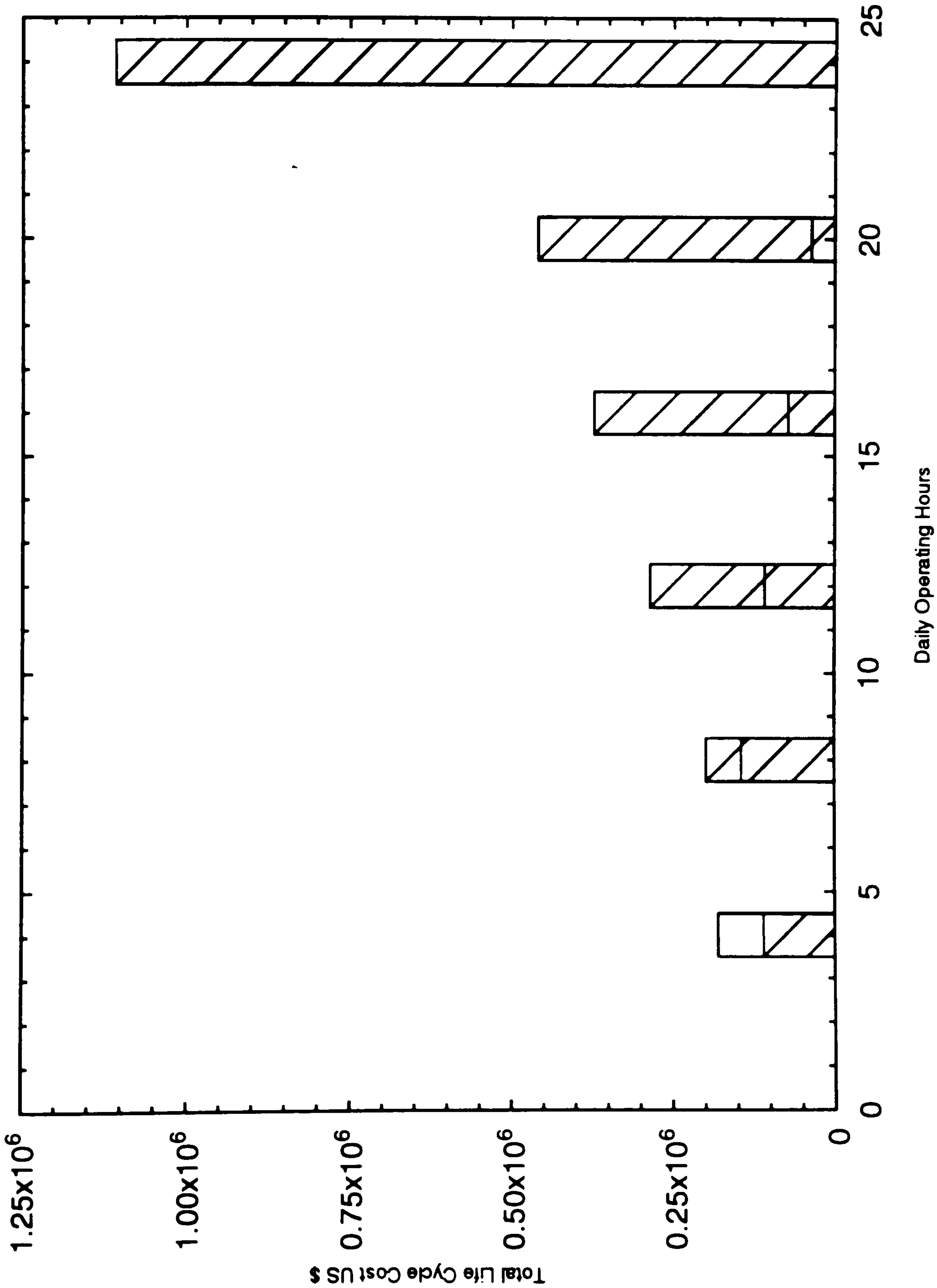


Figure 6.2 PV's Installation & Operational Cost for Various Array Peak Power

TABLE 6.2 - INSTALLATION & OPERATIONAL COST FOR VARIOUS PV ARRAY PEAK POWERS AS SHOWN GRAPHICALLY IN FIGURE 6.2

IN US DOLLARS ($)	P4	P6	P7	P8	P9	P10	P11	P12
OH = 4hr	69,040	17,795	286	12,981	1,500	9,554	109,656	4,386
OH = 8hr	138,000	35,585	568	12,981	1,500	9,554	198,198	7,928
OH = 12hr	206,960	53,364	854	12,981	1,500	9,554	285,213	11,409
OH = 16hr	275,920	71,133	1,137	12,981	1,500	9,554	372,225	14,889
OH = 20hr	344,800	88,975	1,422	12,981	1,500	9,554	459,232	18,369
OH = 24hr	758,560	319,901	5,118	12,981	1,500	9,554	1,107,614	44,305

OH = Daily Operating Hours.

6.2.3 58.8KVA DIESEL POWERED TELECOMMUNICATION SYSTEM DESCRIPTION AND COSTS.

The components and costs of the actual diesel powered telecommunication system at BIA are given below.

6.2.3.1 The Diesel System.

The present operating Lister-Petter, 58.8KVA diesel generators with a power factor of 0.8 is oversized to provide a total DC load of 5.388KW. The excess capacity and reduction in generator efficiency represents an added operating cost. The equipment (except the ACON) operate on DC electricity, with battery back-up, and, thus, the AC power from the generator must be converted to DC for both operating the equipment and battery charging, with the attendant power losses.

From [91] and [98], it has been observed that diesel generators suffer a significant efficiency degradation following start-up and running at partial load. The diesel generator efficiencies were primarily dependent on the load factor from start-up to shut-down. The measured efficiencies were significantly reduced during the first 90 minutes of start-up time or with loads less than their rated output.

As the fraction of diesel use decreases, so does its total operation and maintenance costs. Provided the diesel efficiency is not degraded, diesel cost will decrease linearly with the number of hours in operation. Hence the marginal cost of diesel energy (the increase or decrease in energy cost for a corresponding increase or decrease in diesel output) should be a constant over most of the diesel energy fraction range.

6.2.3.2 <u>Operation of 58.8KVA Diesel Generator and Costs.</u>

The costings presented below are the actual figures involved in operating the diesel generating system at BIA.

D1 = Cost of the present operating CS6 type Lister-Petter 58.8KVA generators = 2 x D186,000.00 ≡ $41,334.
PW (life=6yrs.) = $177,112.
LCC = $218,446

D2 = Cost of transportation & installation of both diesel generators = $820.
PW (life=6yrs.) = $3,514.
LCC = $4,334

D3 = Cost of electrical cables = $950.
PW (life=10yrs.) = $2,035.
LCC = $2,985

D4 = Annual replacement of oil & fuel filters = 2 x $360.
PW = $19,109.

D5 = Annual replacement of (2 x 300) litres of engine oil = $934.
PW = $24,788.

D6 = Annual maintenance of exciter groove = 2 x $667.
PW = $35,404.

D7 = Annual flushing of radiator = 2 x $178.
PW = $9,448.

D8 = Annual fuel consumption of (2 x 39,000) litres
= $43,334.
PW = $1,150,084.

D9 = Annual maintenance runs of vehicles to site
= $13,780.
PW = $365,721.

D10 = Annual manpower cost = $13,643
PW = $362,085

D11 = Total Life Cycle Cost (LCC) = $2,192,404.

D12 = Annualised LCC (LCC/25yrs) = $87,696.

All costings were obtained in local currency and then converted to US Dollars.

The costs involved with the diesel generating system are illustrated in figure 6.3.

6.2.3.3 <u>Cost Reduction due to Reduced Operating Hours.</u>

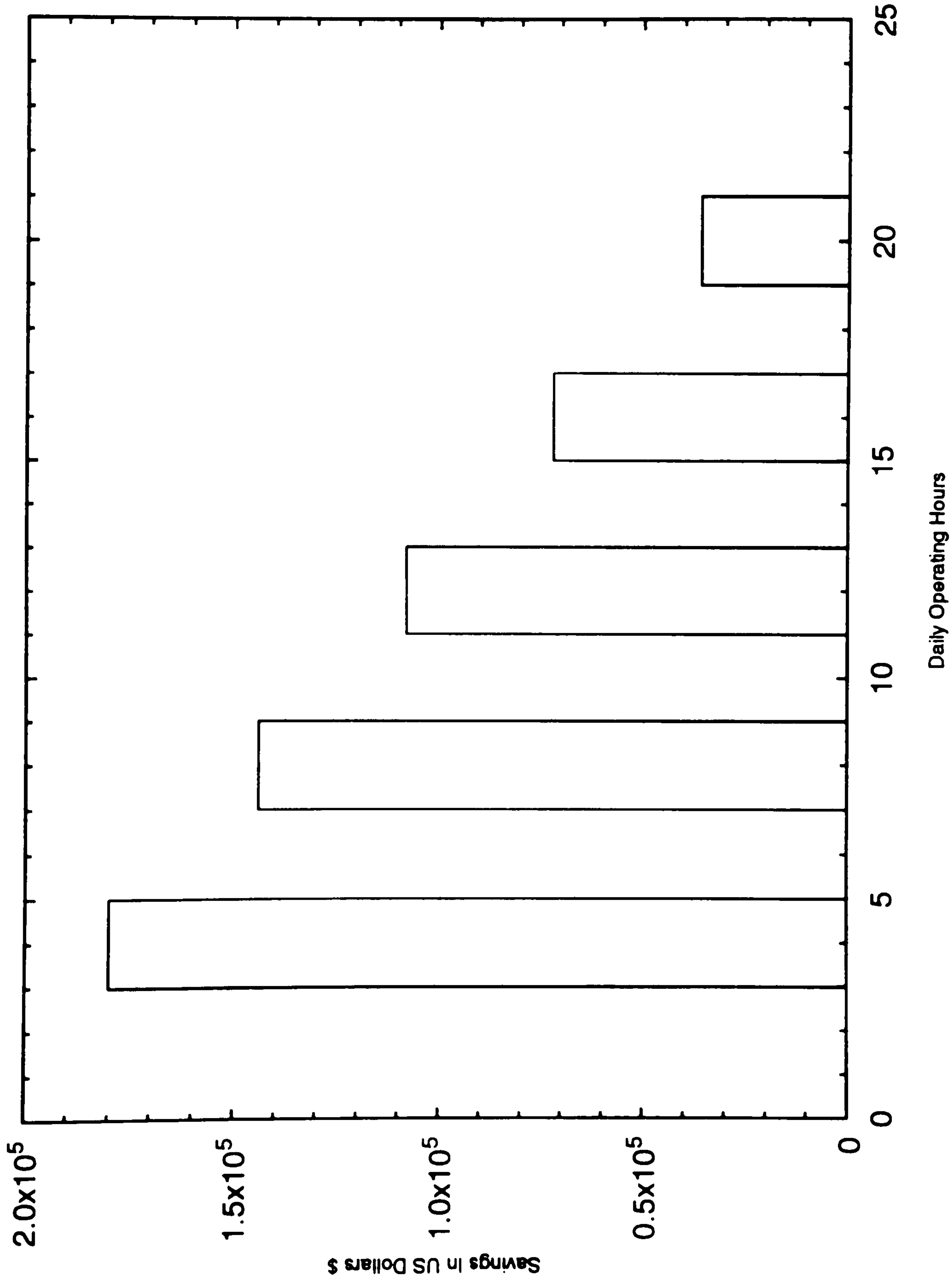
This section will quantify the amount of savings to be realised in operating the diesel generators for 4, 8, 12, 16 and 20 hours a day. If the generators operate for a total of 20 hours a day, the increase in their life span would be about 16.7%. Below is given the total savings of the 58.8KVA diesel generator being operational for 20 hours each day.

S1 = Annual savings on replacement of oil & fuel filter
= $120
Total savings = 4 x $120 = $480 (for 4 years)

S2 = Annual savings on engine oil = $156
Total savings = 4 x $156 = $624

S3 = Annual savings on maintenance of exciter groove
= $223
Total savings = 4 x $223 = $892

Figure 6.3 58.8KVA Diesel Generator's Operating Hours Versus Total Savings



S4 = Annual savings on flushing of radiator = $59
Total savings = 4 x $59 = $236

S5 = Annual savings on fuel consumption = $7,237
Total savings = 4 x $7,237 = $28,948

S6 = Annual savings, vehicle maintenance runs to site
= $1,200
Total savings = 4 x $1,200 = $4,800

S7 = Annual savings on manpower cost = $0

TABLE 6.3 - 58.8KVA DIESEL GENERATOR'S OPERATING HOURS VERSUS SAVINGS (FIGURE 6.3).

US ($)	S1	S2	S3	S4	S5	S6	S7	TOTAL SAVINGS
OH=4	2,400	3,118	4,460	1,180	144,740	24,000	0	179,898
OH=8	1,920	2,496	3,568	944	115,792	19,200	0	143,920
OH=12	1,440	1,872	2,676	708	86,844	14,400	0	107,940
OH=16	960	1,248	1,784	472	57,896	9,600	0	71,960
OH=20	480	624	892	236	28,948	4,800	0	35,980

OH = Daily Operating Hours.

6.2.4 OPTIMUM PV/DIESEL HYBRID SYSTEM WITH CURRENT OPERATING 58.8KVA DIESEL SYSTEM.

There is a need to identify an optimum PV system which will form a hybrid system with the present operating CS6 type 58.8kVA diesel generator at BIA. The diesel generators have another 4 years of useful life to operate before they are due to be replaced. It is interesting to know whether it would be economically beneficial to include a PV system in the present operating system. A hybrid system will reduce the operating and maintenance cost of the diesel generator system. The PV hybrid system would be economically viable if the savings in operational and maintenance cost of the current diesel generators are greater than the total annualised cost of the PV system at the end of the 4 year period.

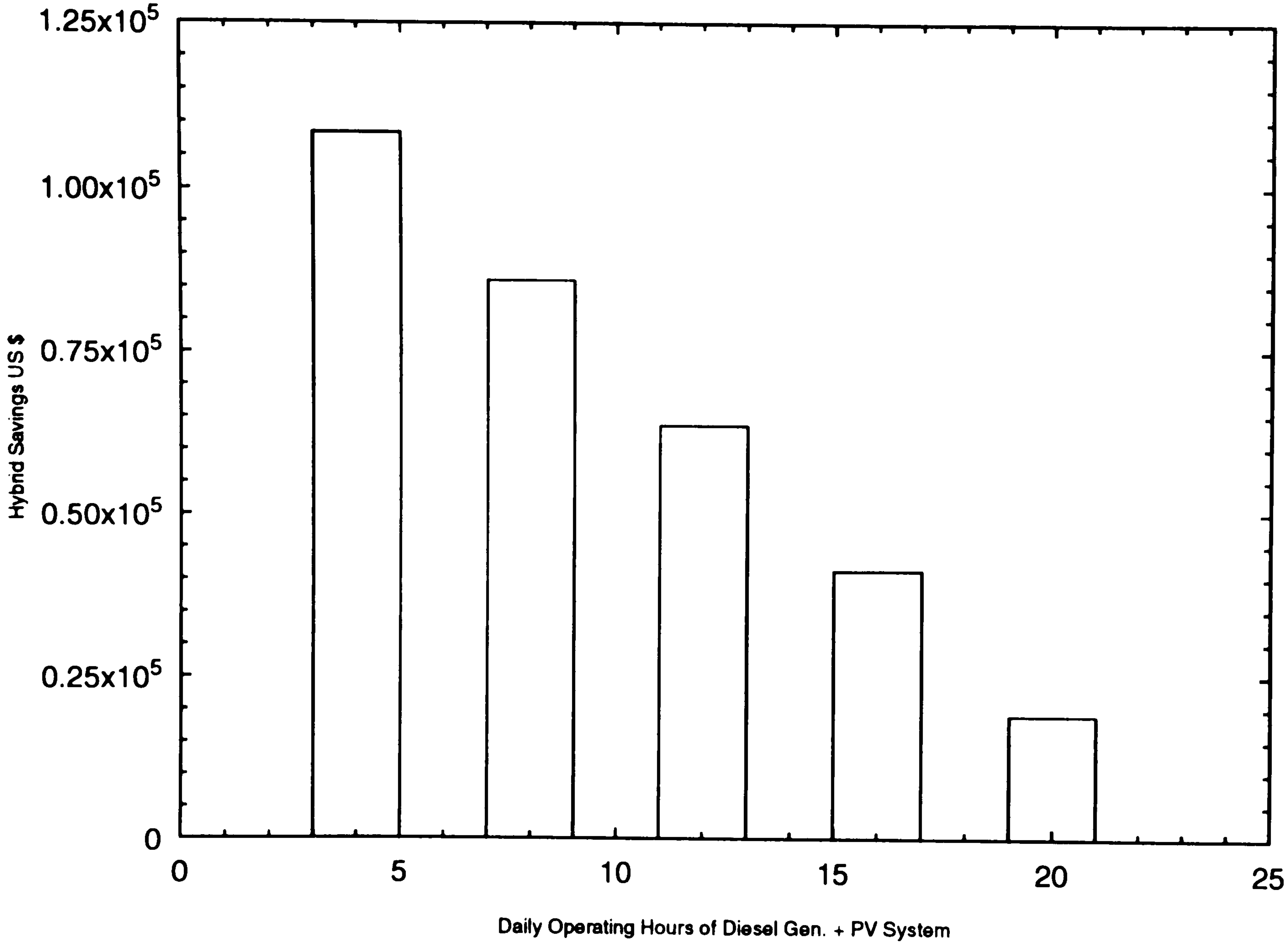
6.2.4.1 Costings of PV and 58.8KVA Diesel Generator.

The present operating 58.8KVA diesel generators are oversized for the load, hence increasing the operating and maintenance costs. Table 6.3, gives the amount of savings to be realised if a PV hybrid system of various size is incorporated. The diesel generators are due for replacement in about 4 years time. An economic assessment of the hybrid system within a 4 year period incorporating the present operating diesel generating system is presented in table 6.4 and an illustration is given in figure 6.4.

TABLE 6.4 - ECONOMIC ASSESSMENT OF HYBRID SYSTEM WITHIN A 4 YEAR PERIOD USING PRESENT OPERATING DIESEL GENERATING SYSTEM (FIGURE 6.4).

Daily Operating Hours Diesel / PV	PV's Annualised System Cost for 4 years ($)	Diesel's Savings on O&M costs ($)	Diesel's Additional Salvage Cost after 4 Years ($)	Hybrid Savings
4 / 20	73,476	179,898	2,000	108,422
8 / 16	59,556	143,920	1,600	85,964
12 / 12	45,636	107,940	1,300	63,604
16 / 8	31,712	71,960	1,000	41,248
20 / 4	17,544	35,980	600	19,036

Figure 6.4 Economic Assessment of Hybrid System - Present Diesel Gen. + PV



6.2.5 OPERATION OF PROPOSED 9.6KVA DIESEL GENERATOR AND COSTS.

In about 4 years time the present diesel generators would be due for replacement. The optimum strategy when replacing the present diesel generator sets would be to install a PV system plus a smaller diesel generator to form an optimum PV/diesel hybrid system.

The smallest available generator to satisfy the load and batteries is a 9.6KVA generator, supplying a continuous output of 7.68KVA and costing $4,048 C.I.F. Banjul.

The costings below are the anticipated amount for operating a Lister-Petter 9.6KVA diesel generator at BIA.

A1 = Lister-Petter 9.6KVA diesel generator (C.I.F.)
= $4,048.
PW (life=6yrs) = $4,048 x 4.28 = $17,325
LCC = $21,373

A2 = Transportation & installation = $520
PW (life=6yrs.) = $520 x 4.28 = $2,226
LCC = $2,746

A3 = Electrical cables = $930
PW (life=10yrs.) = $930 x 2.14 = $1,990
LCC = $2,920

A4 = Annual replacement of oil & fuel filters = $336
PW = $336 x 26.54 = $8,917

A5 = Annual replacement of 100 litres of engine oil
= $156
PW = $156 x 26.54 = $4,140

A6 = Annual maintenance of exciter groove = $375
PW = $375 x 26.54 = $9,953

A7 = Annual flushing of radiator = $125
PW = $125 x 26.54 = $3,318

A8 = Annual fuel consumption of 29,784 litres = $16,547
PW = $16,547 x 26.54 = $439,157

A9 = Annual maintenance runs of vehicles to site
= \$10,335
PW = \$10,335 x 26.54 = \$274,291

A10 = Annual manpower cost = \$13,643
PW = \$13,643 x 26.54 = \$362,085

A11 = Total Life Cycle Cost (LCC) = \$1,128,900

A12 = Annualised LCC (LCC/25yrs) = \$45,156

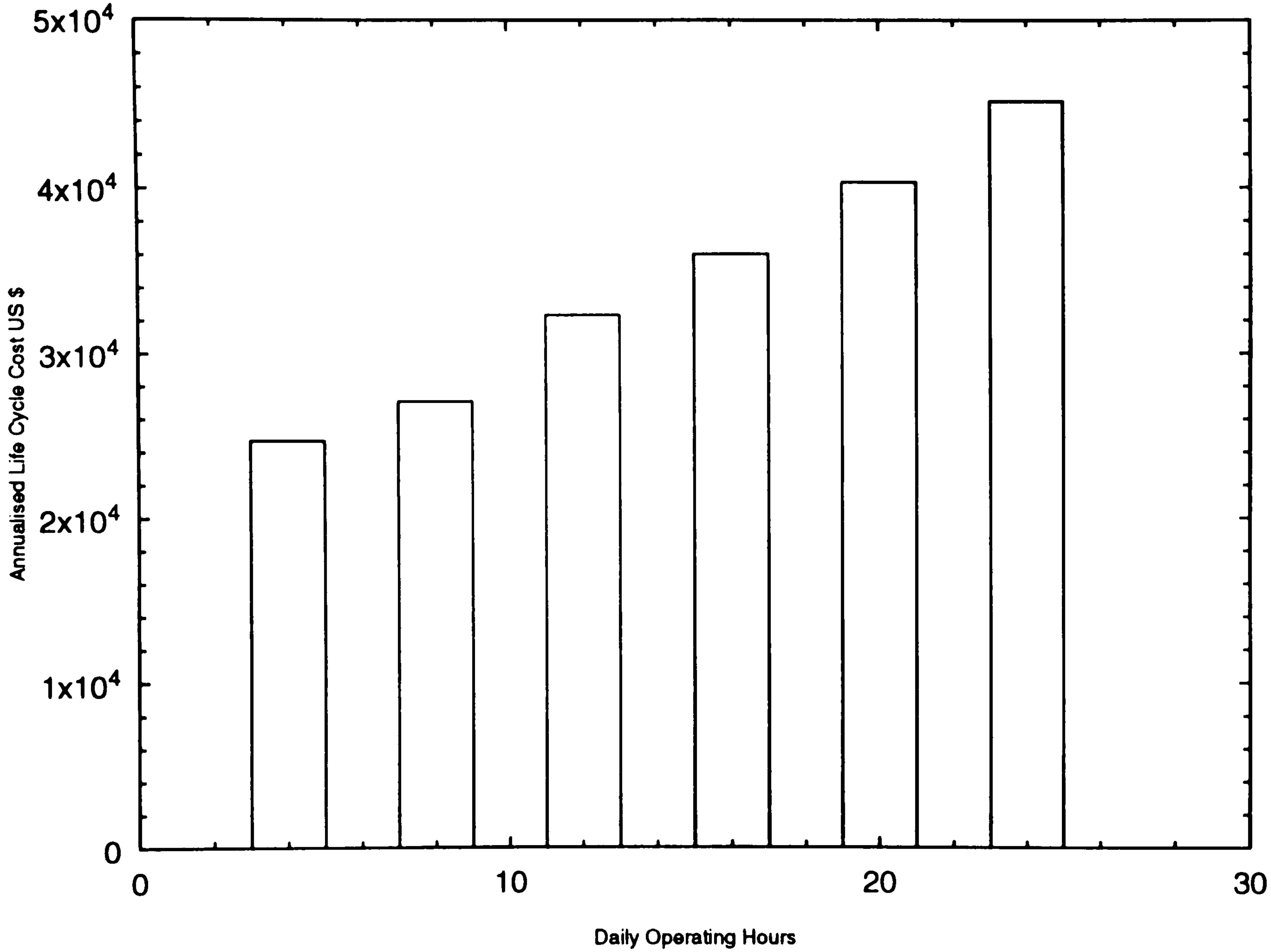
All costings were obtained in local currency and then converted to US Dollars.

The costs involve with the proposed 9.6KVA diesel generating system are given in table 6.5 and illustrated in figure 6.5.

TABLE 6.5 - 9.6KVA DIESEL GENERATOR'S INSTALLATION & OPERATIONAL COST FOR VARIOUS OPERATING HOURS (FIGURE 6.5).

US ($)	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
OH=4	12,792	1,633	2,920	3,583	1,659	4,034	1,354	177,898	110,247	301,733	617,853	24,714
OH=8	12,711	1,633	2,920	4,299	1,991	4,830	1,619	213,483	132,302	301,733	677,526	27,101
OH=12	12,670	1,633	2,920	5,149	2,389	5,786	1,937	256,191	158,762	362,085	809,517	32,381
OH=16	17,123	2,200	2,920	6,184	2,866	6,927	2,309	307,413	190,504	362,085	900,531	36,021
OH=20	21,373	2,746	2,920	7,431	3,450	8,307	2,760	368,879	228,589	362,085	1,008,540	40,342
OH=24	21,373	2,746	2,920	8,917	4,140	9,953	3,318	439,157	274,291	362,085	1,128,900	45,156

Figure 6.5 9.6KVA Diesel Generator's Installation & Operational Cost



6.2.6 PV/DIESEL HYBRID SYSTEM.

The aim of the hybrid system is to maintain an optimum operating system that will yield the lowest energy and operational cost. The cost effectiveness of the hybrid system is determined by comparing the Present Worth (PW) of the PV capital, maintenance and operational cost to the PW of the displaced diesel, maintenance and operational costs.

In order to avoid degrading the diesel generator efficiency and hence reducing the benefits of the hybrid system, the PV system must be designed to be able to satisfy both the load and the battery system for a period greater than the "start-up degradation" period during the day. The benefit of the hybrid system is also increased by ensuring that the diesel generator is operated when the PV and storage systems are unable to satisfy the load.

The diesel generator must be operated periodically in order to keep it in good operating condition, hence avoiding additional costs. In reference 97, this period is taken as every fortnight for four hours or until the batteries are almost fully charged. In addition the diesel generator operates whenever the PV/battery combination is incapable of meeting the load and should be for a period of 4 hours or more.

It is essential for a hybrid system at BIA to deliver a cost benefit that is greater than the LCC associated with the installation and operation of the proposed PV system. This cost benefit could be obtained from the LCC benefit realised from savings in fuel use, operation and maintenance of the diesel generators.

Economic analysis [99] has indicated that PV stand alone powered communication systems are viable for low power applications, but for high power demand, diesel is recommended. It has also been shown that improved technical and economic performance is achieved by an optimised PV/diesel hybrid system [97]. The combination of the two power sources leads to a reduction of the disadvantages of each one used individually and increases the overall reliability [100].

6.2.6.1 Analytical Energy Cost of Hybrid System.

The total energy cost of the hybrid system (ECH) is given as follows:-

$ECH = f_p*PEC + f_d*DEC$ ....Equ.(1)

where f_p and f_d are the fraction of PV and diesel energy produced respectively and PEC and DEC are the total diesel and PV energy costs respectively.

The fraction of the PV and diesel energy produced is given in equations (2) and (3) respectively.

$f_p = TE_p/(TE_p+TE_d)$ ....Equ.(2)

$f_d = TE_d/(TE_p+TE_d)$ ....Equ.(3)

where TE_p and TE_d are the total energy produced by the PV and diesel systems respectively.

From equation (1), PEC and DEC could be split into fixed and variable terms.

For the PV system the fixed term costs are the minimum array structures, electronic controllers, design and installation. The PV array and batteries are considered to be linear with the amount of energy produced. In the case of the diesel system, the fixed costs are the generators and control panels, transportation and installation. These costs are incurred irrespective of the period of operation of the system.

Combining equations (2) and (3), substituting it into (1) and denoting F and V for fixed and variable costs. Equation (1) now becomes;

$ECH = (1-f_d)*VPEC + FPEC + f_d*VDEC + FDEC$ ....Equ.(4)

The total energy cost of the hybrid system (ECH) is a function of the fixed costs, but the fixed cost is independent of f_d, and does not influence the derivative of ECH with respect to f_d, over its valid range [97].

$d(ECH)/d(f_d) = VDEC - VPEC$ ....Equ.(5)

If the variable cost of diesel energy, VDEC, is greater than the variable cost of PV energy, VPEC, the total energy cost will decrease for decreasing f_d. Also, if VPEC is greater than VDEC, then the most economical system is not to use PV.

6.2.6.2 Energy Cost of Proposed Hybrid System.

The energy cost of the proposed hybrid system is obtain from the combination of tables 6.2 and 6.5. The result is shown in table 6.6 and the minimum annualised cost of the hybrid system is $41,990. The optimum hybrid system is obtained from figure 6.6, when the daily operating hours of the PV and diesel generator are 16 and

8 hours respectively. The proposed PV/diesel hybrid system for BIA is shown in figure 6.7.

TABLE 6.6 - TOTAL COST OF PROPOSED HYBRID SYSTEM (FIGURE 6.6).

DAILY OH PV + D.GEN	P11	P12	A11	A12	TOTAL COST ($)	ANNUALISED TOTAL COST ($)
0h + 24h	---	---	1,128,900	45,156	1,128,900	45,156
4h + 20h	109,656	4,386	1,008,540	40,342	1,118,196	44,728
8h + 16h	198,188	7,928	900,531	36,021	1,098,719	43,949
12h + 12h	285,213	11,409	809,517	32,381	1,094,730	43,790
16h + 8h	372,225	14,889	677,526	27,101	1,049,751	41,990
20h + 4h	459,232	18,369	617,853	24,714	1,077,085	43,083
24h + 0h	1,107,614	44,305	---	---	1,107,614	44,305

See Appendix 1 for the actual costings of the PV and diesel system for BIA.

Figure 6.6 Total Cost of Proposed Hybrid System

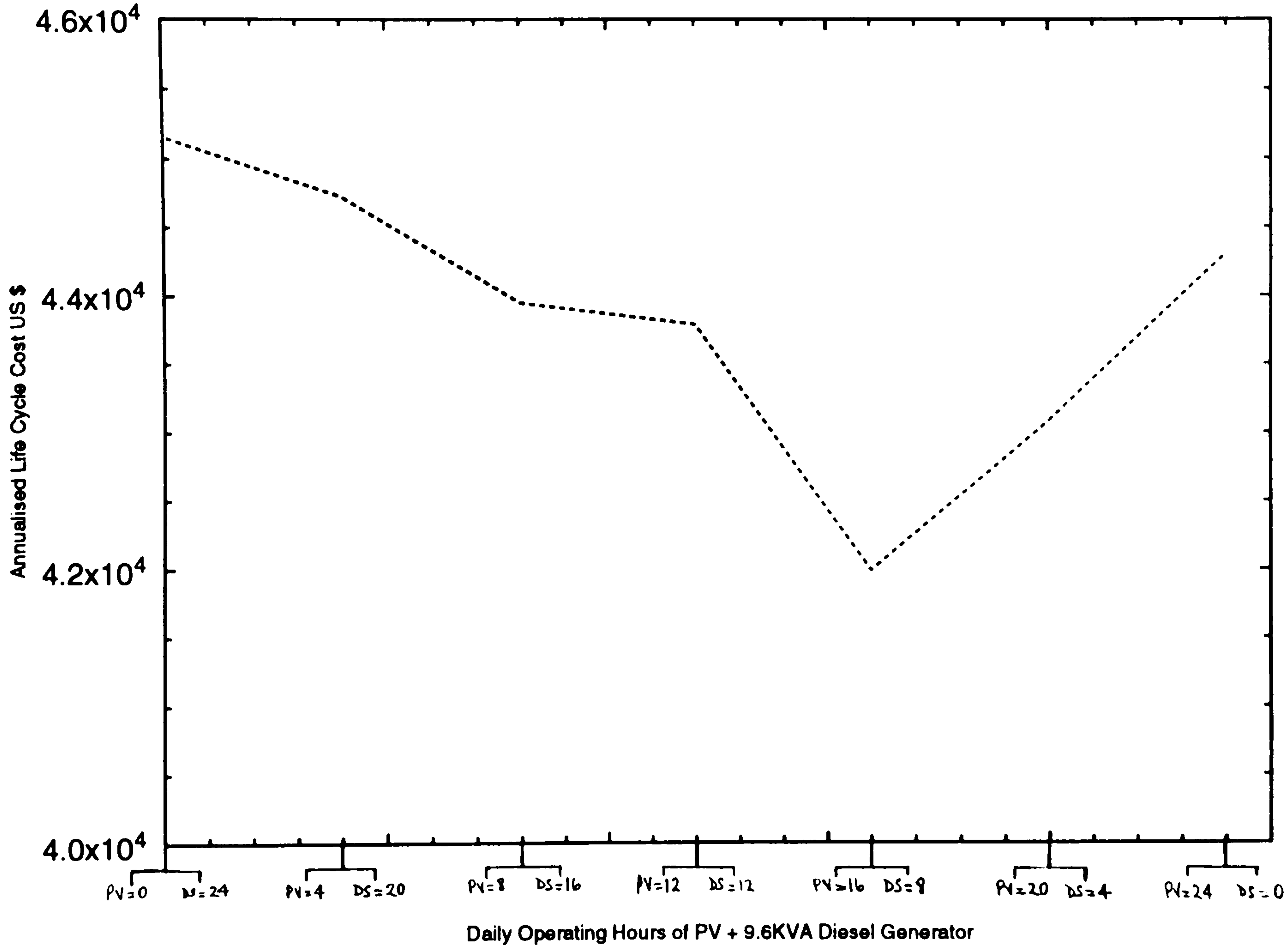
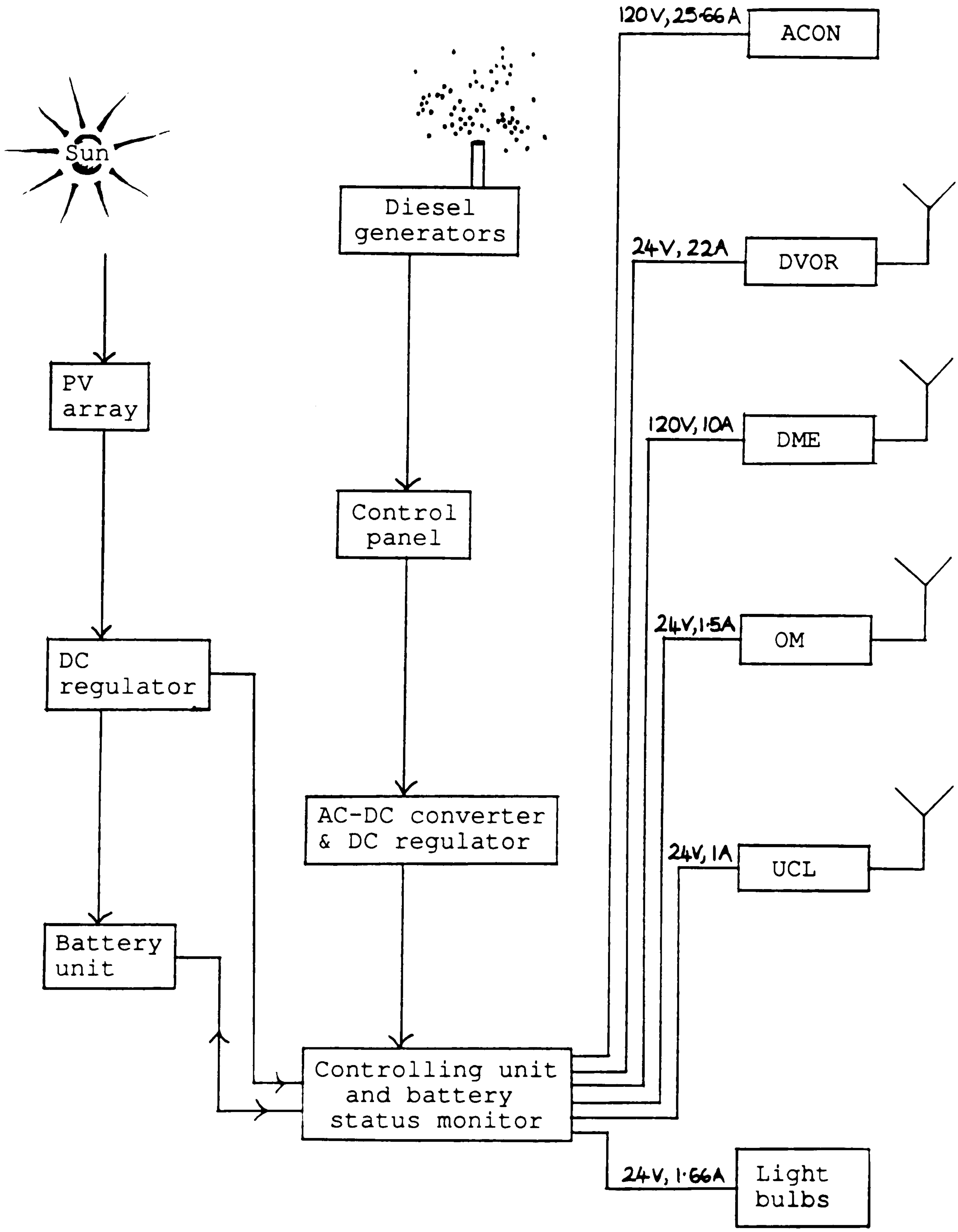


Figure 6.7 The proposed PV/diesel hybrid system at BIA.



6.3 CONCLUSION AND RECOMMENDATIONS.

It could be observed from sections 6.2.2.3 & 6.2.3.2 that the total life cycle cost (LCC) of the stand-alone PV (SAPV) system and the 58.8KVA diesel system for BIA are $1,107,614 and $2,192,404 respectively. Hence the respective annualised LCC for both system are also given as $44,305 and $87,696. These figures indicate that the proposed SAPV would be less expensive than the current diesel generating system on a least cost life cycle basis.

It is worth mentioning that the economic analysis did not take into consideration such factors as human and environmental benefits, where PV does not add to environmental pollution like conventional energy sources. It is extremely difficult, if not impossible, to quantify the human and environmental cost of diesel systems. If this cost was quantifiable then the full economic benefit of PV for BIA would have been even more apparent. This also makes PV even more attractive for use at BIA.

The present 58.8KVA diesel generators at BIA are too large for the load demand. The oversizing of the diesel generators, hence reducing generator efficiency, represents an added operating cost. For the proposed hybrid system, it is recommended to purchase a much smaller generator that will be just able to satisfy both the load and the battery system simultaneously.

The proposed configuration of the PV/Diesel hybrid system for BIA is found to be cost effective at daily operating hours of 16 and 8 respectively. Hence the PV system should be designed to supply an average daily power for 16 hours.

Economic analyses have indicated that PV powered stand alone communication systems are viable for low power applications, whilst for high power demand a diesel or conventional energy source is recommended. Better performance with high reliability could be attained with an optimised PV/diesel hybrid system.

CHAPTER 7

7.0 TECHNOLOGY TRANSFER TO DEVELOPING COUNTRIES AND ASSOCIATED PROBLEMS.

Chapter seven defines technology transfer, the model of technology transfer, the needs for technology transfer and its associated problems.

7.1 INTRODUCTION.

It is believed that one of the major conditions for development is access to new technology. If developing countries are to become industrialized, the overwhelming part of such technology must be imported, at least in the initial stages [101]. Thus, in recent years, technology transfer has had a vital role to play and, according to UNESCO [102], it has been seen as the panacea for the economic ills of many countries regardless of their stage of development.

Technology, if properly managed, narrows the technological gap between developed and developing countries [103]. However, without generating the skills and resources to apply the transferred technology as well as the social measures to accept it, imported technology can be counter productive, only creating dependency on foreign suppliers and increasing national debts [104]. This is a situation that the Gambia should be particularly aware of if it is to develop an indigenous capability in PV.

7.2 DEFINITION AND CONCEPTS OF TECHNOLOGY TRANSFER.

Although "Technology Transfer" (TT) has become an accepted expression in many types of literature, its precise meaning has not been defined within stated boundaries. The word "transfer" is simpler in meaning, while "technology", more imprecise, has been defined by Root as "the body of knowledge that is applicable to the production of goods and the creation of new goods" [105]. Dajani [106] and Stewart [104] refer to technology as "either a device or process of doing things".

The Organisation for Economic Cooperation and Development (OECD) defines "transfer" as "the process by which science and technology are diffused through human activity" [107].

Al Tayyeb [108], defines technology transfer as "the purposeful diffusion and adaptation of a designed capability from a source to a destination".

A "transfer of technology" encompasses any activity in which a supplier makes technology available and a recipient adopts it. For the technologies to be appropriated successfully, hard technologies like machinery, equipment and factories will usually be accompanied by complementary soft technologies like expertise, organization and management methods, maintenance and Research and Development (R&D) capacities. This will enhance the adoption of new techniques and their future improvement. This is a scenario for the case of PV which is an evolving technology requiring constant improvement.

Equally, the transfer must take place in an appropriate economic environment, which presupposes the availability of necessary infrastructures and supplies, adequate market and profitability prospects. When compared to other forms of exchange of goods and services, technology transfer stands apart, owing to the complexity of the appropriation process. The recipient must identify needs, deal with the choice of technologies, appropriate and adapt the chosen technology, and deal with management and manpower. The paramount need for the Gambia is adequate and appropriate energy for sustained socio-economic development.

There have been many successful transfers of technology from developed to developing countries. Any failures in recent decades, however, have arisen from situations which were excessively unbalanced. Although the suppliers may have fully understood the technology and everything concerning it, and possibly even transfer procedures, still the recipients have found themselves at a disadvantage in the process of acquiring and adopting the technology.

The transfer of technology process is generally categorized into four areas for discussion:

(1) transfer of "modern" or "simple" technology,

(2) "planned" or "unplanned" transfers,

(3) "vertical" or "horizontal" transfers and

(4) "bundled" or "unbundled" technology transfers.

7.2.1 SIMPLE OR MODERN TECHNOLOGY TRANSFER (TT).

The difference between "simple" and "modern" TT is that the former is referred to as "lower" or "current" technology [109], whilst the latter is referred to as "higher" or "most-up-to-date" technology [110]. This latter type is mainly characterized by automation resulting from considerable research and development and involving high capital investment like sophisticated product ranges such as biogenetic materials [111].

PV is a modern technology. The improvement and development of solar cells involves intense R&D with high capital investment in terms of equipment, machinery and manpower. The production of modules is a much simpler process, requiring simpler and much cheaper equipment and a lower level of training in the process operatives. The installation and maintenance of PV systems is an even lower level technology, requiring lower levels of training. Thus, within this modern technology, the parts to be imported and those to be supplied indigenously can be matched to the capabilities of the host country.

One of the main advantages of this technology is that it is very simple to use and can operate in the most remote parts of the world with minimum maintenance. The users of PV systems therefore need only the simplest training to get the best out of their systems.

7.2.2 PLANNED OR UNPLANNED TT.

"Planned" transfer of technology refers to the purposeful systematic acquisition of advanced appropriate foreign production techniques thus promoting the economic development process [112]. "Unplanned" transfer on the other hand is a kind of uncontrolled slow or spasmodic transfer which just happens, often by personal contacts [113].

As PV is a technology that has to be planned, the appropriate infrastructure must be in place.

7.2.3 VERTICAL OR HORIZONTAL TT.

The "vertical" component of TT represents the flow of ideas upwards from basic research through applied research and from invention to production, and downwards in the reverse direction [107]. "Horizontal" TT takes place when the organized exchange of information is from one place (source) transferred to another which may or may not be located in the same country [114].

PV needs both "vertical" and "horizontal" TT to enable the technology to develop further. Most of the "vertical" TT will take place in industrialised countries, at least in the near future, whilst "horizontal" transfer takes place into the developing countries. It is important however that developing countries are able to monitor and understand the "vertical" TT so as to make the optimum choice of the technology to be transferred horizontally for their use. Centres of expertise in the developing countries are important in this regard.

7.2.4 BUNDLED OR UNBUNDLED TT.

The "bundled" (or packaged) TT is the transplant of an entire production unit with capital and management, in contrast to other modes in which the supply of technology is "unbundled" (or unpackaged), where, for example, one process in a production line of many processes may be upgraded by technology transfer [115].

In the case of PV technology, the transfer of unbundled PV system technology is best suited for developing countries with some technical capability. As the indigenous "PV capability" grows over time, the "unbundling" may extend back up the process chain to module production and eventually to cell production if conditions make this cost-effective.

7.3 MODELS OF TECHNOLOGY TRANSFER.

Technology transfer occurs because of the existence of sellers (called "transferors") and buyers (called "transferees"). Consequently, there are many models through which technology can flow from transferor to transferee, so creating the third important element in the transfer process [112][115]. Many diversified models or channels have been in use to transfer technology from the developed to developing countries [116]. Technology transfer channels are usually divided into two categories:-

(1) Commercial channels or models of transfer - this involves physical or tangible capital assets [117].

(2) Non-commercial channels or models of transfer - this involves scientific or technical knowledge that facilitates the productive use of physical assets and the skills and know-how necessary for productive workers and managers [117].

7.3.1 COMMERCIAL CHANNELS OR MODELS OF TRANSFER.

These forms of transfer are usually through an "enterprise-to-enterprise" arrangement. These are given below:-

(1) Foreign Direct Investment (FDI)

(2) Joint Ventures

(3) Licensing Agreements (including patents, know-how, trade names)

(4) International Subcontractings

(5) Turnkey Contracts

7.3.1.1 FOREIGN DIRECT INVESTMENT (FDI).

This model of transfer was the classical, nearly universal, form used by foreign enterprises in former colonies and even in independent countries [118]. Until towards the end of the 1960s and early 1970s, the establishment of the wholly-owned foreign subsidiary or the majority-owned foreign affiliate was the predominant method of foreign expansion by Multi-National Companies (MNCs) [111][119].

The major features of foreign direct investment are given below:-

(a) Various elements of the technology are supplied in "bundled" or "packaged" form [120]. The transfer, apart from the accompanying technological flow of specific production technology, also includes:-

(i) marketing expertise,

(ii) managerial skills,

(iii) engineering design.

(b) It enables the technology supplier to retain ownership and to exercise control over the new production plant [112].

(c) It provides entry into a domestic industry by a foreign firm, e.g. it involves the creation of a subsidiary by the parent multinational company in a host country [111].

(d) It involves the flow of productive capital from one country to another [115][117].

There are several motives for the foreign investor to use FDI as a vehicle for transferring technology:-

(1) Foreign firms take advantage of the local conditions such as low wage rates and low raw material costs, e.g. Japanese MNCs "farm out" the production of technologically simpler components to South-East Asian countries, using labour intensive techniques.

(2) Foreign firms provide, through local rather than distant home production, fuller coverage of local markets.

(3) Foreign firms use FDI when their domestic home market is saturated and the demand for their products has slowed down.

(4) Foreign firms, competing abroad, are at a disadvantage in relation to competition from their host country and they use FDI to limit or reduce that disadvantage.

(5) Foreign firms invest abroad to overcome the problems of trade friction, e.g. Japanese MNC's shift production plants to developed nations so providing local employment and obtaining a local/continental market.

It is believed that international firms prefer direct investment to licensing where:-

(a) the financial and human resources are available,

(b) control over present and future market development is desirable,

(c) the firm fears licensing will result in the give-away of valuable know-how or will threaten its position in established markets,

(d) the transfer involves a broad line of products or is an integrated part of marketing and financial management,

(e) the technology is highly complex or the foreign affiliate lacks industrial sophistication and the transfer requires a prolonged and sustained relationship to effect the transfer, or

(f) there is a concern over protecting the product standards or trade name [121].

According to Behrman, FDI creates a growing dependence on foreign technologies and discourages the emergence of indigenous capabilities for technological development [122]. Hellinger's opinion [123] is that technology transfer by this method, without adaptation of technical knowledge by the host (in this case the Latin American countries), resulted in increased unemployment, inequality and dependency. These are lessons to be learnt by other developing nations and the Gambia in particular. It should also be noted that, recently, to rectify a situation like the one mentioned by Hellinger, the "Nepal Foreign Investment and Technology Act" was established. This includes skill formation as one of the criteria on the basis of which FDI is considered by the competent authority in the country [124]. Others are of the opinion that FDI promotes the rate of diffusion of technology and accelerates development [120][125]. Sharma's study claims that there is evidence that FDI has been a blessing in the rapid industrialization process of South-East Asian countries, without producing any of the harmful side-effects [125].

Although there is still an on-going debate as to the usefulness of FDI for the host country, there are advantages for the recipient worth mentioning:-

(1) Recruitment of local labour force.

(2) Creation of new job opportunities.

(3) Transfer of financial resources.

(4) Raising of technological and educational levels of the labour force.

(5) Transfer of technical and managerial skills.

(6) Benefits to research and development institutions.

In the case of the Gambia, FDI would be recommended for the manufacturing of solar cells and PV modules. This is mainly because of the investment costs, skills and infrastructure which would be involved. There is little doubt that FDI would benefit the Gambian economy at its present stage.

7.3.1.2 Joint Ventures.

Developing countries are becoming aware of the difference between mere geographical or interfirm transfer and genuine indigenous assimilation of technology with mastery, control and improved ability to gain future autonomy. They have been striving to find ways and means to "unbundle" package deals. As an alternative to FDI, several levels of "unpackaging" have evolved and the most significant one takes the form of "Joint Ventures" [119]. Later it became clear that joint ventures had become far more important as a vehicle of overseas investment by MNCs than FDI [126]. Joint venture is defined by Hagedoorm in [127] as "a business association between two or more parties who agree to share the provision of equity capital, the investment risk, the control and decision-making authority, and the profits or other benefits of the operation". Host countries usually insist on having a higher share (in order to prevent the control that exists in FDI) than that of the foreign firms to give local governments or firms an influential role and assure a certain equality of position among partners. Ilgen and Pempel in [117] mentioned that joint ventures are the most promising route for successful technology transfer for those developing countries with adequate capital and commitment to development because of the benefits they offers to the host country. Some of the benefits are as follows:-

(1) Transferring of scientific knowledge and advanced technology.

(2) Training of local employees and acquiring of managerial skills.

(3) Solving of discrepancies is facilitated due to a certain equality of both partners involved and risks are shared.

(4) Gaining from the expertise of the foreign investor in all aspects (e.g. acquiring know-how, exporting to foreign markets, etc.)

(5) Generating technological spin-offs and productivity spill-over.

Another cited potential advantage of joint ventures, is the ability to balance the interests of the technological adapter and developer with the potential user of the technology, although suppliers of high technology (MNCs in large part) have traditionally been reluctant to transfer what they consider "core" technology (i.e. unique or proprietary know-how) to non-controlled firms overseas [128][129].

Two important conclusions can be drawn about joint ventures:-

(1) The core technology is not "leaking out". MNCs are not selling the most up-to-date technology.

(2) Developed countries receive newer advanced technology than developing countries do.

Any form of joint venture that brings investment into the Gambia with socio-economic benefits should be welcomed. Joint ventures with Gambian entrepreneurs could be established in the area of PV module assembly and Balance-of-System (BOS) manufacture.

7.3.1.3 Licensing Agreements.

When a foreign firm wants to avoid any risks involved in setting up an affiliate in an other country, the preferred model of transferring technology is mainly through a licensing agreement. Under this agreement certain specific rights of access to a technology conferred on the acquirer for a specific duration may consist of authorization to use industrial property rights, secret know-how, patents, trademarks and technological assistance [127][130]. Payments for licensing disembodied technology take a variety of forms, e.g. royalties, lump sum fees, a share in profits and payments on an "as-used" basis.

Japan, at the very outset of industrialization, put emphasis on manpower development which made it possible for her to continue to absorb and duplicate advanced technology autonomously and to rely on technology transfer in "unbundled" form, mainly through licensing contracts [111]. Transfer via licensing, however, is only of benefit to the nation if transfer is limited to products or processes that the nation is capable of producing or using at internationally competitive costs, or products serving purely domestic markets, for which neither imports nor exports are an option [101][132]. India, for example, pursued a policy of developing a domestic machine tool industry through judicious licensing from suppliers in the industrially advanced countries. By the late 1970's India's Hindustan Machine Tools had produced machine tools of ever-increasing sophistication and diversification [133].

The success of Japan and India is in their ability to absorb, utilize effectively and improve the transferred technology. Padgett in [134] noted that "A good licensee can contribute technically as well as financially to the business of the original licensor, in some cases ensuring that he stays ahead of the competition". In spite of its merits, licensing agreements do contain clauses which imply conditions on the licensee's use of technology and of the products made from it, e.g. limitations on the markets allowed for export, tying clauses for the purchase of inputs and raw materials, limitations on the location of manufacture, etc. [135].

Among the stronger forces influencing foreign firms to licensing as a means of transferring technology are:-

(1) A rather short expected "life-cycle" for a product and a host market which may be too small to attract investment.

(2) Fear of political or economic risks, or the law of the host country rejects FDI

(3) Benefits are gained through cross-licensing for reciprocity [companies exchange licensing to supplement

their research with licensed technology or to avoid patent protection].

(4) Additional earnings from technologies are obtained when the period of competitive advantage in the home market has passed.

Gambian companies thinking of licensing some parts of the PV technology, must ensure that all the necessary infrastructure is in place, so that Gambian products would have a performance and cost which is competitive with imported products.

7.3.1.4 International Subcontractings.

In this arrangement, a foreign manufacturing enterprise subcontracts the manufacture of certain parts or the assembly of finished products, using inputs and technology supplied by the foreign firm, to another enterprise in the developing country. The transfer of technology, e.g. specifications, production know-how, machinery and equipment, depends on the capacity of the subcontractor to produce parts according to the detailed specifications and instructions of the contracting enterprise. If the subcontractor is able to undertake the manufacturing activities with few of the foreign personnel or without any at all, there will be considerable knowledge which can be transferred for the manufacturer of parts or for installations. However, no explicit payments for technology are involved, since it is the foreign corporation that pays the subcontracted firm for the work carried out. None the less, subcontracting can be considered a channel for transferring technology, since there is always the possibility that technological spin-offs may be generated for the local enterprise involved. Subcontracting in developing countries is concentrated in clothing, electronic equipment and components.

MNCs sometimes prefer subcontracting part of their PV module assembly to countries with low wages and basic infrastructure since this part of the manufacture is more labour intensive. The production of PV consumer products in Hong Kong started in this way. PV manufacture could be subcontracted hence generating employment with economic benefits.

7.3.1.5 Turnkey Contracts.

This model is an example of a "highly packaged" form of transfer in which bundled technological knowledge is combined. The foreign contractor firm undertakes the responsibility for carrying out all of the activities (e.g. includes provision of process know-how, supply of complete plant and equipment, initial training of process operators, infrastructure, etc.) required for the planning and construction of a discrete project in the host country. Turnkey contracts are defined as "operations which are basically sales to a host country by a foreign firm of plants including equipment and technical assistance [130]".

In many circumstances the turnkey package method is the most practical way for transferring technology, because:-

(1) It is specially suited to the first stage of industrial development, since developing countries usually lack local skilled manpower and resources [111][112].

(2) It gives direct access to all supportive resources of the foreign firms [111].

The bundled way of supplying technology to developing countries is controversial and Japanese policy makers in the early stage of development realized that the acquisition of "highly packaged" transferred technology has to be kept to a minimum for several reasons [111]:-

(1) Mastery of technology cannot be bought, it has to be learned. Thus, in the case of turnkey plants, local technical personnel were not involved from the initial process design phase and indigenous R&D inputs, required to improve and adapt technologies, will be minimized [136].

(2) Technological dependence arises when most of a country's technology comes from abroad and greater reliance is on the foreign technology, hence greater dependence. To avoid such dependency, Ozawa in [137] states that "developing countries have in recent years been unbundling the package of technology supplies so as to acquire them separately from different sources".

(3) "Packaged" transfer gives the technology supplier monopolistic advantages such as, for example, switching the collection of profits from one source to another with relative ease, or imposing higher prices compared to "unpackaged" transfers [112].

7.3.2 "NON-COMMERCIAL" CHANNELS OR MODELS OF TRANSFER.

These mainly take place through an "intermediary". Some of the most obvious channels are as follows:-

(1) Exchange of information at international conferences, trade fairs, official organisations (e.g. universities).

(2) Purchase of equipment and machinery and related literature.

(3) Transmission of know-how and managerial skills related to commercial channels of transfer.

(4) Employment of foreign experts and consultancy arrangements.

(5) Exchange of personnel through technical assistance programmes.

(6) Education and training of host country's labour force.

(7) The flow of books, journals, films and other publications.

(8) The movement of persons from country to country, e.g. travel, immigration, exchange of students and experts.

Almost all developing countries suffer from a shortage of skilled labour necessary for successfully absorbing and processing the exogenous technologies, due to either a lack of trained local personnel or to the "brain drain". To help alleviate the former problem, there is a need to train local manpower in vocational and technical institutes, on-the-job training or sending students overseas. These different categories in subsections 7.3.1 and 7.3.2 of technology transfer are often mutually complementary and overlapping to some degree. The choice of acquiring technology is influenced by a variety of factors:-

(1) The outlook and motivation of local enterprises.

(2) The nature of the technology itself.

(3) The level of skills of personnel and industrial capabilities of the host country.

(4) The level of absorption and assimilation of the technology embodied in foreign commodities (e.g. intensity and capacity of R&D of recipient, strength of existing infrastructure in the host country, etc.).

(5) The size of the supply market and pattern of consumption of the technology importer.

7.4 NEEDS OF TECHNOLOGY TRANSFER.

The aspects involved in the transfer of technology can be classified under two main headings. One concerns the terms and conditions under which such transfer takes place, whilst the second concerns the suitability or appropriateness of the technology thus transferred.

7.4.1 TERMS AND CONDITIONS FOR TECHNOLOGY TRANSFER.

7.4.1.1 <u>The Cost Element.</u>

Singer in [138] refers to the market of technology as "an extremely imperfect one" or "one-way street" because, firstly, it is almost entirely monopolized by the industrial countries, giving them the right to sell or not to sell, and the price is subject to bargaining skills. Secondly, the country importing the technology often does not have sufficient knowledge of alternative technologies available, nor has it the national capacity for debating technical matters on equal terms with the experienced foreign transferor [112].

Developing countries argue that the achievements of science and technology should be "the common property of mankind" and, subject to proper protection and payments to the inventor, should be made freely available [115][138]. But technology is not a "free good" developed for the benefit of humanity which can be made available as a gesture of philanthropy (human welfare). It is a captive business developed for profit and although there are no really authoritative figures for the total cost to developing countries of transferred technology, it is believed that the annual payments (in the form of "embodied" purchases) made by host countries for acquired technology are very high. The cost element of transferred technology varies depending on which channels are used. Much of the cost is concealed, since the import often takes place as a part of a package or in "embodied" form.

For foreign multinational corporations using the "packaged" FDI model of transfer, initial costs are very high, but they will eventually subside, once the production process has started. Goreish in [114] considers "packaging" as a form of price discrimination where the supplying party aggregates various technologies (of varying quality, efficiency or other performance characteristics) in one bundle and obliges the acquiring party to purchase the whole bundle at one price.

Some unpackaging of technology leads to reduction of costs, although it requires a great deal of expertise (e.g. experience and trained manpower) to unpackage a technology. Therefore, for channels of "unbundled" transfer, such as joint ventures, licensing contracts, etc., the cost is determined on terms stated by the experienced transferor and the expertise of the transferee [112][138].

Costs occurring through technology transfer are classified as "direct" and "indirect" contractual transfer costs:-

(1) Direct.

Payments are stated in the contract between transferor and transferee:-

(i) Charges for the right to use patents, licences (i.e. payments in form of royalties), know-how and trade marks.

(ii) Charges for technical information and know-how required (e.g. payments paid for hiring foreign experts).

(2) Indirect.

Payments are not necessarily stated in the contract between transferor and transferee:-

(i) Over-pricing of inputs of intermediate goods, some of which may not have a market price (due to the absence of appropriate negotiating powers of the transferee).

(ii) Charges through profits on capitalization of know-how (e.g. shares).

(iii) Charges through part of the repatriated profits of wholly-owned subsidiaries, or joint ventures, the establishment of which does not make specific provision for payment for the transfer of technology.

Direct costs are relatively straight forward to establish. The indirect costs are much more "hidden" and therefore difficult to discover and calculate. It can be inferred from this that evaluating the cost of technology transfer is a fairly complicated process.

7.4.1.2 Goodwill of Both the Transferor and the Transferee.

There are various reasons for the transferor to favour transferring technology in the form of joint ventures, FDI, licensing etc. into developing countries [139][140][141]. Some of these are:-

(1) To obtain additional earnings from technologies whose period of competitive advantage in the home market is over.

(2) To lower production costs by capitalizing either on the new international division of labour or on cheap raw

materials, and thereby maintain competitiveness in world market.

(3) To improve the corporate image by not losing contact with developing countries.

(4) To gain access to markets with protectionist barriers.

In order to attain benefits from global technological progress, developing countries opt for acquisition of foreign technology, as long as it is:-

(1) A means for forming a basis for domestic technological development, i.e. it has to be suited to the environment of the host country. (For example, Some developing countries have a high rate of unemployment, so the transfer of labour intensive technologies is more suitable [115]).

(2) In line with resource endowments and the socio-economic development objectives of the host country [142].

(3) Generating a significant "learning by doing" and "learning by using" effect, including the transfer of managerial skills and marketing rights (i.e. spill-over effects) [143][144].

(4) Not applied to restrictions and prohibition on the adaptation, e.g. preventing the use of imported technology as a basis for local R&D development [138].

7.4.1.3 Level of Physical and Technological Infrastructure.

Developing countries must develop and modernize their infrastructure at great expense, because buying technology can either be the most useless outlay or the best of possible bargains depending upon the transferee's ability to make good use of it [112][145]. The existence of a sound infrastructure (e.g. adequate schooling facilities, ports, road and rail systems, etc.) is generally an essential ingredient for accomplishment. Another "ingredient" of value is the national institutional infrastructure in the area of transmission of technology which includes a variety of government facilities such as technical and engineering schools and training programmes, quality-control services, etc. The operation of these facilities on a viable basis is essential for the healthy growth of national technological capabilities [146].

7.4.1.4 Research and Development (R&D) Effort.

Another essential element, according to Sharif in [112], which should be given high priority for a successful technology transplant is a minimum investment on R&D expenditure by the acquiring party. R&D can be distinguished in either "applied research" (also "adaptive research"), i.e. directed to the adaptation and modification of imported technology, or in "basic research" (also "pure research"), i.e. concentrating on original invention [147]. For developing countries, the import of technology has to be parallel to applied domestic R&D efforts; Sharif in [112] claims that "transfer of technology can never be a wholly adequate substitute for independent R&D activities. The two can most fruitfully complement each other". Ozawa agrees in [148] by saying, "postwar Japanese industry itself exerted a great deal of effort to adopt and assimilate imported technologies. This assimilative effort initially stimulated adaptive R&D, which later turned more original in orientation". Bright in [149] states "R&D expenditures have played a major role for technical self-reliance in the industrialized world". According to Singer in [138], "if technological power is measured by the money spent creating it then at least some 95% of technological capacity rests with the industrial world". Therefore, it is urgent for developing countries to establish proper local R&D facilities or take measures for improving the existing R&D institutes. The urgency is due to the following facts:-

(1) To improve the performance of economic activities by using the imported technologies effectively.

(2) To adopt and later to adapt and assimilate foreign technologies with regard to local endowments (e.g. market, consumer's needs, etc.).

(3) To aim at the pursuance of "reverse engineering" (i.e. the operation by which a given product is taken apart in order to achieve an understanding of its components and their functions. The resulting knowledge

can be used to duplicate or to develop a locally superior version of it).

(4) To gain the ability in building up an indigenous technological capability, so reducing "dependency" on foreign technology and perhaps eventually achieve technological self-reliance.

An expansion of science and technology activities requires a base of highly qualified scientists and engineers. To counteract the problem of "brain-drain", material and social incentives have to be introduced and adequate research laboratories have to be established both to motivate research scholars to stay in their homeland and to tempt back those who have emigrated [112].

7.4.1.5 Effective System of Education.

Efficient "human capital" or "software" in the form of technical, engineering and management skills in the host country are needed to exploit fully all advantages from transferred technology. According to Dahlman and Westphal in reference 150, "skill and human development occupy the highest position in reaching technological capability leading to technical self-reliance". Thus, an appropriate educational system is a prerequisite to providing an adequate pool of qualified skilled manpower [103].

Developments in South Korea provide an example of successful acquisition of technological capability, based on selective transfer of technology from overseas

[103][111]. Local technological capability can be developed through skill formation.

Skill formation can be achieved through:-

(1) Establishing adequate formal educational and training systems (schools and universities) to improve literacy at all levels.

(2) Establishing a national infrastructure of technical schools, engineering colleges and on-the-job training in existing industries, but also, through the training component of the technology transfer transaction, achieving high levels of workers' skills.

(3) Expansion of resources on R&D and S&T (scientific and technical research) through local firms and/or government supported research institutes.

Developing countries need more of middle-level skills and technicians who can contribute most towards the selection, unpackaging, adaptation and utilization of received technology. There is also a need for highly qualified professionals to manage and direct these middle-level skills and technicians. In particular there is a need for a centre of expertise which understands international technical developments and can relate these to the needs of their country.

In addition to the terms and conditions mentioned above, Cetron in [140] adds some others, such as suitable government policies, market size and demand and availability of financial resources.

7.4.2 APPROPRIATENESS OF TRANSFERRED TECHNOLOGY.

It is important to note that technology is not a unitary entity, and different technologies have quite distinct characteristics; they are also influenced by environment, custom, culture, resources, climate, etc. [112]. Various terms have been used to describe "appropriate technology". Schumacher in [151] called it "intermediate technology". Brown in [152] calls it "a technology that should fit well into the socio-economic, cultural and environmental surroundings of the people it is intended to serve". Mathur in [153] discusses "a third world technology which consists of an adaptation of modern methods to the special conditions of the developing world". Modern technology, which is the necessary base for industrialization, is essentially controlled by a very small number of the most advanced nations, and has been primarily developed to serve their economies and consumer life-styles. Therefore, a successful transfer of technology is not a matter of transferring "hardware" only from one geographic location to the other. It involves much more subtle issues of selection and a capacity to adapt and modify before the technology can function properly in its new surroundings [142][154]. Salomon-Bayet in [155] maintains that "the transfers of technology require the preparation of education, management and production structures appropriate to the mastery of production of knowledge and know-how themselves". To what degree the adaptation of advanced technology is necessary depends on the size of the "suitability" or "appropriate technology gap" or the ability for the host to "bridge the technological distance". For many developing countries the suitable technology is in fact for production of basic products.

Thus, the process of adaption is greater. Chudson stated in [156] that, "some production techniques and equipment are usually adapted to the skills of the local labour supply and market requirements i.e. smaller, less sophisticated equipment is usually used for production and product designs are modified to suit local market conditions". Quoting from Schumacher in [151], "the transfer of an intermediate technology instead of a highly sophisticated one would be immensely more productive in developing countries, because of the size of the technology gap". On the other hand, some economists disagree and there is an on-going debate on Schumacher's concept of "small is beautiful" versus the well-publicized trend of "the bigger the better". They believe that "catching-up requires modern technology" [103]. The following are some of the arguments given for the use of modern technologies in developing countries:-

(1) Modern (new) technologies are generally more productive and efficient than intermediate (old) technologies.

(2) Advanced technologies exert modernizing influences on the society and improve the quality of workers and management.

(3) Capital-intensive modern industries allow much profit to be made, which in turn may be used to promote further

growth. Multiplier effects of capital-intensive industry are advantageous in the long-run.

(4) Advanced technologies allow integration into the world-wide (ever more specialized) division of labour.

However, not all the available advanced technologies can be easily adapted to suit the factor endowments of the host country. The inappropriate nature of advanced-country techniques for underdeveloped countries arises from the differences between the economic and institutional environment. Technology designed in advanced countries does reflect their overall technological conditions, with the consequence of increased costs and/or decreased efficiencies when it is transferred [138][142]. Thus, the ability of the importer to repair, maintain, modify and adapt the new technology effectively is crucial. Furthermore the scale of production is matched to the size of market, and the market in many developing countries is much smaller than that in Europe, USA or Japan.

The process of identifying, evaluating and selecting the appropriate technology to be acquired from abroad presupposes information and expertise to judge the merits of the technology and the best means for its acquisition [112]. Therefore, the existence of appropriate institutions (centre of expertise) are essential in carrying out the evaluation of the transfer policies in order to accomplish maximum benefits from the transfer of technology.

7.4.2.1 Environmental Problems associated with Industrial Technology Transfer.

Industrial development may have the following effects on the environment:-

(1) A contribution to the deterioration of the ozone layer through the use of Chloro Fluoro-Carbons (CFC's) and other harmful gases.

(2) The contamination of soil and waters (rivers and lakes) from mining practices, the dumping of solid and liquid wastes, infiltration, etc..

(3) Industrial pollution arising from the emissions of toxic gases and uncontrolled emissions.

(4) Accidental spills of toxic products, with a host of adverse effects such as the contamination of soil, freshwater, oceans and the hazards to human and animal health.

At present, the principal industrial polluters are the industrial countries but developing countries could easily become major polluters if they do not avail themselves of "clean" technologies in the future.

7.4.2.2 Sustainable Industrial Technology Transfer.

A great many problems of industrial pollution are related to equipment and technologies which have been in place for many years and are now often obsolete. Replacing these production tools (machinery, factories, etc.) may create additional benefits to the extent that more environmentally sound technologies may also be more productive. However, unless the capital costs of this replacement are assumed by an international organisation or institution, it is unlikely that such a replacement will take place, at least on a large scale because of the high cost of capital and the small market for the products. The very fact of using such equipment to produce and operate makes know-how technologies particularly attractive, as they may generate important economic and environmental gains.

With regard to new technological acquisitions resulting from increased investments and revenues, any additional costs must be offset by an increase in productivity. If not, funding from an external organism must provide the impetus.

Developing countries must develop strategies to aid the transfer of technology process for socio-economic development. The form and type of TT to choose would vary from country to country depending on the situation prevailing in the country. A strategy for transferring the PV technology into the Gambia using already discussed models of TT is given in chapter eight.

7.4 CONCLUSION.

Technology transfer is the exchange of hardware and technical knowledge (in the form of physical knowledge and human-capital) among different geographical locations for the purpose of adaptation and use in new functions and production units. It comprises all those activities in which a supplier makes technologies available, and a recipient adopts them to his own needs. For the recipient to do so successfully, usually the transfer of hard technologies (machinery, factories and equipment) must be accompanied by complementary soft ones (expertise, organisation and management methods, maintenance capacities and adequate R&D) to allow the adaptation and integration of techniques. This implies that the transfer must be made in an appropriate economic environment in which the necessary infrastructures are in place, needed supplies are available, and market and profitability perspectives are adequate. Another important facet is its impact on non-technical areas such as government policies, domestic and international marketing, education, social values and others.

There are difficulties in differentiating between various models (e.g. licensing, joint venture, etc.) of technology transfer because as a rule one or a combination of these are used to suit a specific problem. The greatest benefit derived from technology transfer is the saving in time and man hours spent in discovering technologies that are already known. Developing countries, in order to attain socio-economic progress, need to select technologies appropriate to their factor proportions, level of development and development strategies. This could be either a transfer of "intermediate small-scale" or "modern large-scale capital intensive" technologies. However, after importation of an appropriate technology, measures that require constant attention, such as skill and human development, training, R&D, etc., must be undertaken to develop further the ability to produce new technologies leading to eventual self-reliance. Otherwise the imported technology will soon become outmoded and will be of less value to the host country. Dahlman and Westphal in reference [150] state that "the acquisition of technological mastery (that is of the ability to make effective use of technological knowledge) is critical to the achievement of self-sustaining development".

The creation of an indigenous PV capability in the Gambia involves some form of TT. Well planned strategy is essential in maximising the benefits of TT.

CHAPTER 8.

8.0 STRATEGY FOR ACCELERATED DIFFUSION OF PV IN THE GAMBIA.

This chapter will assess the relevant criteria for the Gambia to acquire PV technology. It will also put forward and discuss proposals for obtaining a successful PV dissemination in the Gambia.

The Gambia has an "energy source" crisis, with insufficient electricity generating capacity in the major towns and cities and, frequently, no supply in rural areas. Around the urban areas (i.e. from Banjul to Brikama), the demand for electricity is high and the electricity generating companies, the Utilities Holding Corporation (UHC) and Management Services Gambia Ltd. (MSG), are unable to meet this high demand, resulting in load shedding and serious power fluctuation. A frequently mentioned source of inexhaustible energy for the future is the use of photovoltaics or solar cell conversion of the energy contained in sunlight. Sunlight is plentiful, available almost 7-10 hours a day, 365 days per year. Electricity produced by PV can light homes and streets, power loads such as radios, televisions, refrigerators, communication systems, navigational aids, water pumps for drinking and irrigation etc., at lower cost than conventional alternatives like a diesel generator.

Many developing countries are becoming aware of the benefits of PV and its use in solving some of their energy problems. Most communities use very little power and, in certain cases, a daily 50Wh power supply can transform the lifestyle of a family. Only in recent years has research begun to focus on the problems that limit the development of PV systems in this huge potential market. With greater demand, economies of scale will help reduce the high capital outlay for PV systems and provide the manufacturers with greater financial incentive for further research and development into the efficiency, stability and production cost of various PV cells. Cheaper and long-lived PV modules, together with increased awareness of the economic and social benefits they offer, will make a major impact on the growth in the use of solar power. Because the rural areas in the developing countries have very few conventional financing possibilities to purchase these systems, innovative financing schemes are essential to allow people access to well needed PV systems.

8.1 SOME PV APPLICATIONS IN THE GAMBIA.

In recent years, the number of PV installations in the Gambia has increased [23]. However, in order to realise its full potential more viable PV installations need to take place at a much faster rate. Figure 8.1, shows the major towns and cities in the Gambia which could act as regional depots for the dissemination of PV systems. Some of the major PV applications are given below:-

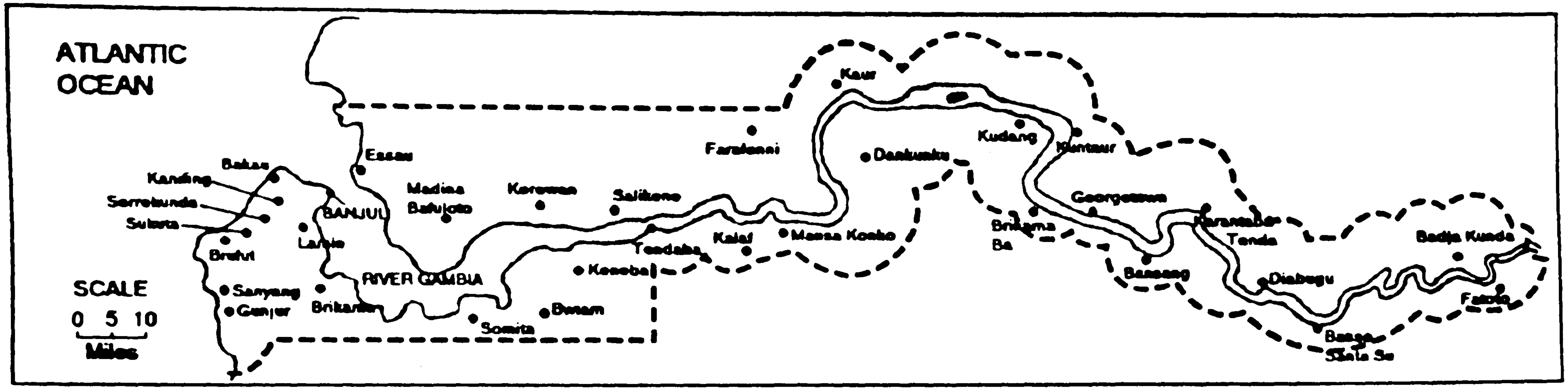


Figure 8.1 Map of the Gambia, showing major towns and cities which could act as regional depots for the dissemination of PV systems.

8.1.1 THE MINISTRY OF HEALTH.

The ministry has completed the replacement of all kerosene/gas operated vaccine refrigerators with solar powered appliances. Some PV lighting systems have also been installed. This involves seventeen health centres, thirteen dispensaries and two mission stations in both the rural and urban areas. Some health centres have solar water heaters and PV powered television and video cassette recorders for use in training nurses on proper health practices. It is envisaged to cover more health centres with similar PV appliances [94].

8.1.2 THE GAMBIA TELECOMMUNICATIONS COMPANY.

The Gambia Telecommunications Company (GAMTEL) has upgraded most of its telecommunication system in the rural areas by:-

(1) converting three of its major UHF amplifier stations from diesel to solar power;

(ii) rehabilitation of existing solar powered VHF systems;

(iii) converting seven telephone exchanges to solar powered VHF systems;

(iv) replacing the old telecommunications equipment at 20 telephone stations with solar powered units.

This improvement has greatly enhanced the communications link between the urban and rural areas with increased reliability and socio-economic benefit for the nation.

8.1.3 THE SAHALIAN REGIONAL PROGRAMME.

Under the umbrella of the regional programme for the use of photovoltaic solar energy in the Sahalian countries (RSP), solar water pumping systems have been installed at sixty-six villages.

8.1.4 EUROPEAN FUNDED PROGRAMME.

The two PV water pumping systems installed on a pilot basis proved so successful that the EC decided to fund further similar projects, currently providing additional water pumping systems for fifty-seven more villages. Also under this on-going project, twenty-two veterinary stations are being equipped with solar freezers and several high schools with PV battery charging systems for their science laboratories.

8.1.5 DOMESTIC APPLICATION.

Several kilowatts of PV power have been installed by private individuals in their homes, offices and farms. The main uses are for lighting, refrigeration, battery charging and water pumping.

From reports received at the Gambia Renewable Energy Centre (GREC), the number of private individuals interested and enquiring about PV systems is increasing daily. The main reason for this upsurge of interest is the frequent power load shedding and an embargo on the installation of electricity from the grid to some newly built houses [56]. With the growth of the tourist industry, certain hotels are considering PV systems and their possible cost-effective deployment.

8.2 OPTIONS FOR THE GAMBIA TO ACQUIRE PV TECHNOLOGY.

PV technology is undergoing continuous technological development mostly in the area of solar cell fabrication owing to efforts directed at reducing solar cell cost per peak watt and gaining greater economic competitiveness as a decentralised energy source. This section will aim to assess the conditions for the Gambia to acquire PV technology, looking at the relevant criteria such as capital and human resources availability, industrial infrastructure and educational environment.

PV manufacture of silicon crystalline solar cells involves basically the following six components:-

(1) Silicon material, electronic grade or solar grade.

(2) Other raw materials.

(3) Solar PV cells.

(4) PV modules.

(5) Balance-of-system (BOS) components and subsystems.

(6) Design and integration of efficient PV energy systems.

The various aspects involved in the acquisition and effective utilization of PV technology by the Gambia are presented below.

8.2.1 COMPONENTS OF PV TECHNOLOGY.

The elements involved with the PV technology, starting from the silicon material to the PV module providing a valuable energy service are itemized below.

8.2.1.1 Silicon Material.

The silicon solar cell manufacturing process involves basically three stages:- (i) Material preparation and shaping, (ii) cell processing and (iii) cell interconnection and encapsulation. The conventional technological process, the flow chart of which is presented in figure 8.2, relies conventionally on the high-purity semiconductor grade silicon (SG-Si) available from electronic industry wastes. In this process, quartzite as a raw material (crystalline form of SiO_2 with over 90% silica) is reduced into metallurgical grade silicon (MG-Si), the purity of which lies in the 98-99% range. MG-Si is purified to qualify as the so-called SG-Si or electronic grade silicon (EG-Si). SG-Si is then melted in a crucible and pulled out to form a single-crystal ingot by using the traditional Czochralski (CZ) technique, which is illustrated in figure 8.3. Ingots are cut into wafers which are etched to remove the damage induced during the slicing operation. Wafers are then processed into a complete solar cell (illustrated in figure 8.4), i.e. junction diffusion, contact elaboration and anti-reflection coating. Finally, cells are interconnected to achieve a practically useful voltage

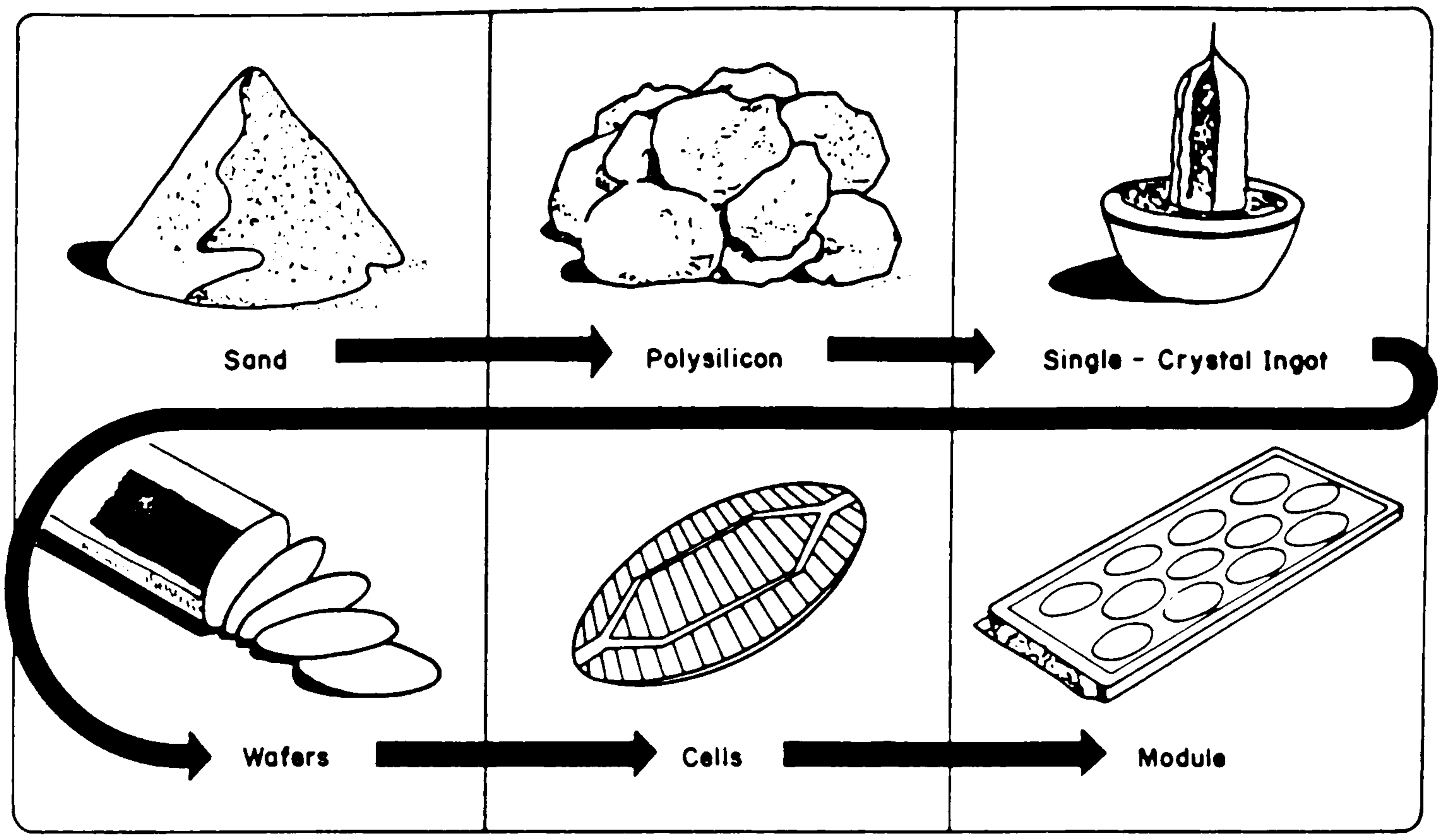


Figure 8.2 Solar cell manufacturing process [73]

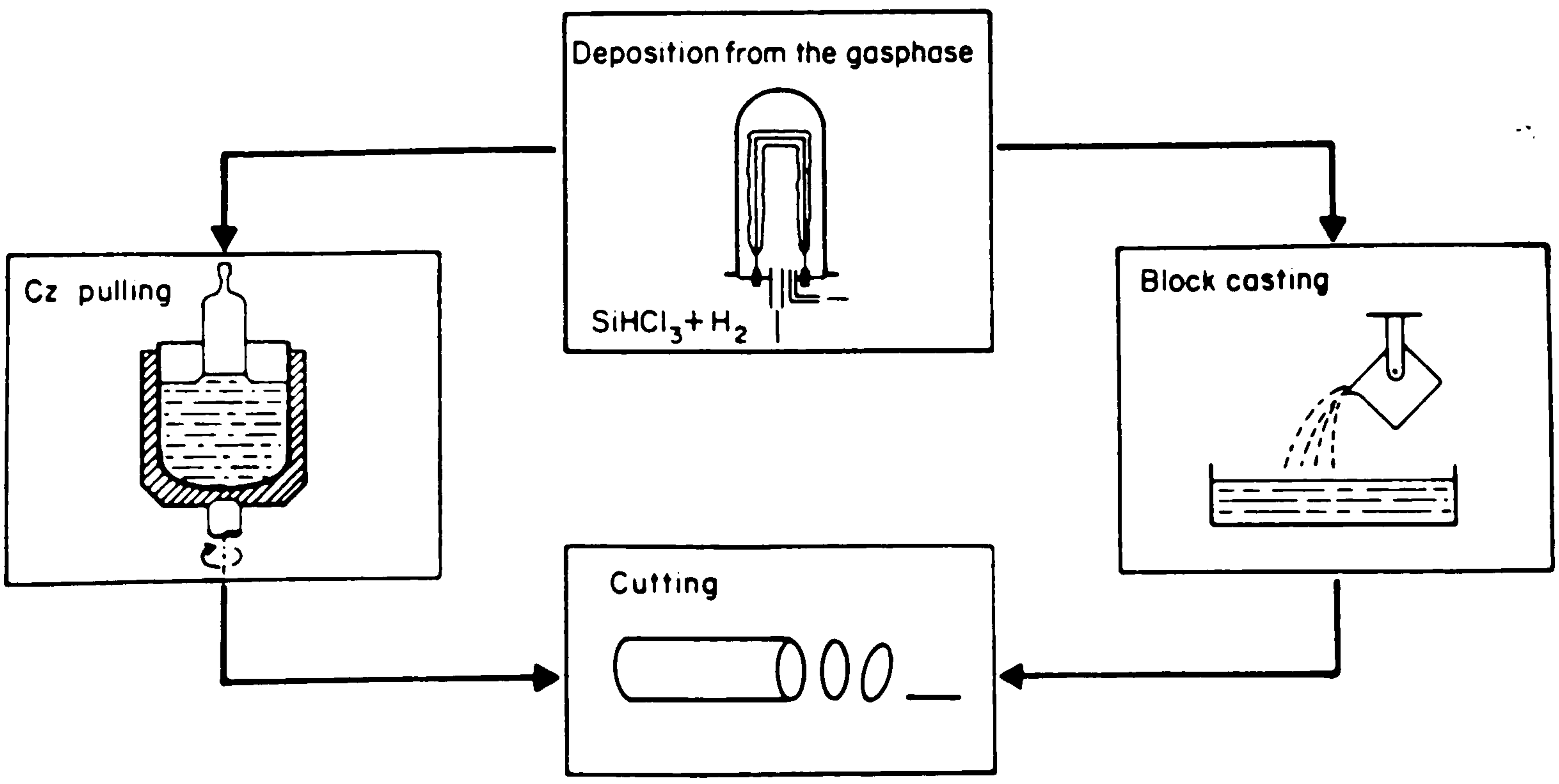


Figure 8.3 Production and slicing of silicon ingots [73]

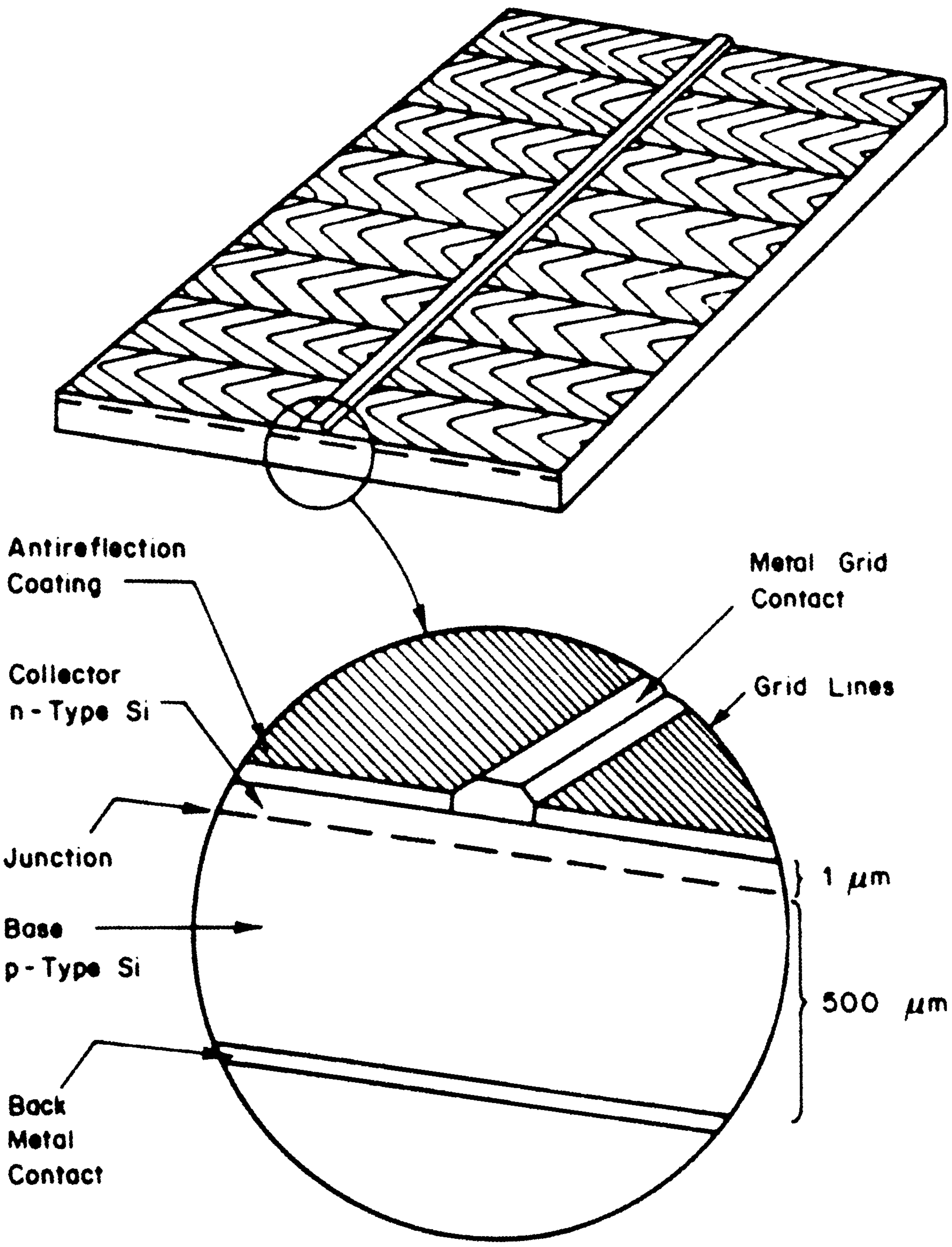


Figure 8.4 A typical single crystal silicon p-n junction solar cell [73]

and encapsulated into a module by using a lamination technique [157].

The preparation of the semiconductor or electronic grade silicon (SG-Si or EG-Si) into wafer or sheet form is the most energy and cost intensive stage of the PV manufacturing stage. The manufacture of EG-Si feedstock through the reduction of quartzite involves highly expensive and complex technology. However the production of wafers from a single crystal silicon ingot, although regarded as high technology, is a relatively simple and adaptable technology [158].

The manufacture of EG-Si and production of silicon wafers in the Gambia can only be done by Foreign Direct Investment (FDI) and most likely would be in a bundled or packaged form of technology transfer (TT). Because of the initial capital involved and the skilled labour force required to man and manage such an industrial enterprise, Gambians cannot afford such a huge cost with a long-term investment perspective. Although labour cost in the Gambia is very low compared to the industrialised nations, this industry normally has low overheads and most of the employees are skilled. Another alternative is through joint ventures but the chances of getting a joint agreement with an internationally established industry could be difficult.

In order for the Gambia to attain this stage of the PV manufacturing business, it needs a high capital flow at low interest and the creation of a highly skilled work force up to university and industrial level. All these conditions are currently lacking in the Gambia.

8.2.1.2 Other Raw Materials.

Some of the raw materials needed in the production of solar cells are summarised below:-

(1) Various chemicals such as acids, alkalis, organic solvents and diffusants.

(2) Conductive paste made of silver and aluminium.

(3) High transmission tempered glass sheets.

(4) Various laminating materials such as Ethylene Vinyl Acetate (EVA) and Tedlar.

(5) Various mechanical and electrical components such as junction boxes and interconnections.

Except for the laminating materials which are produced only by a few companies in the world, the rest could be manufactured in the Gambia. Since most of the above mentioned items are not manufactured in the Gambia, there will be a need to import these items. Presently, there is no industry involved with PV manufacture at this level. There is potential to set up such an industry provided basic training and education is obtained through an inexpensive non-commercial model of TT at governmental level. Initially, a joint venture or a licensing agreement could be undertaken with a company that is experienced in the business and a modern, planned and unbundled TT is recommended.

8.2.1.3 Solar Cells.

The manufacture of high quality solar cells on a commercial scale requires acquisition of proper production equipment suitable for conditions prevailing in the Gambia. The production equipment and machinery which meets all the stringent requirements of large scale manufacture are generally not available off the shelf. The chances of obtaining foreign firms to invest in the Gambia through FDI is very limited, mainly because of the high energy cost and low infrastructural set-up in the country for such firms.

The encapsulation of the cell is a very skilful process. It provides mechanical and chemical protection to the cell and its durability determines the operating life of the module. This stage deserves particular attention with high quality control [158][159].

Most solar cell manufacturers build their own production equipment according to their particular design requirements and manufacturing techniques which may differ from company to company.

Silicon production and solar cell manufacture is very capital intensive and also involves rapid technical developments. It is essential to have large markets for the output in order to be internationally competitive. It is not appropriate for the Gambia to consider such investments unless it could establish itself as the supplier to the whole North-West African sub-region via FDI.

8.2.1.4 Photovoltaic Modules.

PV manufacturing technology based on single crystal or multi grain silicon solar being offered by PV system manufacturers mostly include the stages of production starting from module manufacture to integration of PV systems. The production equipment available for module manufacture must be designed for and be reliable under the conditions in the developing country.

The industrial capability in the Gambia is in a good position to handle this type of production. It mainly involves the soldering together of individual solar cells to form modules followed by lamination. Particular attention is needed in the design and connections of these modules. The design will mainly be geared towards the type of load to be used, especially the voltage, current and impedance of the system to be powered. Setting up this industry is not as expensive as in sections 8.2.1.1 and 8.2.1.2. This could be implemented through internal subcontracting or the turnkey contract model of TT. Funds for this operation could be negotiated with international organisations or Gambian entrepreneurs could decide to invest in such ventures with licences from overseas companies for the technological know-how.

With the turnkey contract, the experienced foreign PV firm must undertake the responsibility to carry out all the activities involved with the supply and installation of all the plant equipment and infrastructure. This includes the provision of process know-how, training, manpower needs, spares, etc for the foreseeable future. Bundled technology transfer must be kept to an absolute minimum, enabling trained personnel to be able to repair the plant to component level.

8.2.1.5 Balance of System Components and Subsystems.

It is extremely important that Balance of Systems (BOS) and subsystems are specifically designed to match the output power of the PV module for optimum and efficient operation of the overall system. The high cost of PV power requires that efficient BOS components be used for cost-effectiveness.

Most PV modules have been found to perform well under stipulated conditions, the usual problem normally arises from the BOS. This has led to some people in the developing countries condemning PV in general. The need for well designed, minimum maintenance BOS cannot be over-emphasized, since in many areas of developing countries the infrastructure for proper maintenance of the BOS does not exit. The BOS components should be well tested, rugged and low maintenance.

BOS components and subsystems are therefore best designed and manufactured in the country of application with due regard to the particular local needs and conditions. BOS components like charge regulators, batteries, inverters, etc., could be manufactured in the Gambia with little difficulty and minimum TT, although, for some modern high efficient BOS, direct contractual TT might be necessary. This has the advantage of being up-to-date with the PV technology business.

8.2.1.6 Integration of PV Systems.

Optimal PV system design must be carried out by local expertise in the country of application since local environmental conditions as well as specific load requirements must be considered for efficient utilization of PV-generated power. The location-specific and load-specific nature of PV power system design therefore make it crucial that design and integration of PV energy systems be carried out by those familiar with local energy needs in all spheres of activity: social, economic and educational.

The overall efficiency and cost-effectiveness of stand-alone PV systems can be increased with an integrated approach to system design and electrical energy utilization. Such an approach can only be attempted by the user country itself since it requires familiarity and understanding of specific local needs, life-styles, economic, social and educational activities as well as local environmental conditions.

It is therefore essential to establish a centre of expertise in the Gambia which can undertake these activities. It is vital for the future development of PV in the Gambia to increase the support given to the Gambia Renewable Energy Centre (GREC). The main function of the centre of expertise is to establish an endogenous capability in PV. This centre of excellence will be a catalyst in the technological development of the country [160].

8.2.2 SUMMARY OF TECHNOLOGICAL OPTIONS FOR ACQUISITION OF PV TECHNOLOGY.

Components of PV manufacturing technology starting from the production of pure silicon material to the finished PV modules and BOS are shown in table 8.1. The level of technical sophistication of the various stages of production is shown in table 8.2. Developing countries like the Gambia can enter into the PV manufacturing industry at any of the stages of production depending on the available industrial infrastructure and technical expertise.

The technology involved in the PV manufacturing processes becomes progressively more complex as it goes back up the path from the final stage, the design and integration of PV energy systems, to the first stage, the production of pure silicon feedstock for solar cell fabrication from quartzite. A particular country therefore has the option to enter into the PV industry along any of the stages starting from the lowest technology of BOS design and development for specific local needs and conditions to the high technology of silicon purification and solar cell fabrication.

8.2.2.1 Options for The Gambia.

The following options exist for the Gambia to obtain PV technology:-

(1) The Gambia could continue as at present to purchase the PV systems from overseas markets, with the design and

integration of the systems performed by local expertise. This strategy could suit the present Gambian market since PV is a bit expensive for some Gambians and technological resources could be considered to be limited. This situation could change in the next few years, when economic activities continue their current growth rate.

(2) The Gambia could opt for increased indigenous manufacture of more efficient BOS. PV modules purchased from other countries could be designed into a complete system together with the locally made BOS components. This generates local employment opportunities, without a need for high investment in PV technology. This also encourages indigenous firms to supply some BOS components, creating competitive market forces which could be to the advantage of the consumer.

(3) Finished solar cells could be imported and assembled locally into modules. A BOS component manufacturing industry will then exist alongside the module assembly industry. This option has the potential of reducing PV system cost without the need for very high investment in an indigenous PV industry. The produced PV system will serve both the local market and the West African sub-regional market. Hence, there is the need for some form of PV marketing strategy, since this option would be cost-effective only if there is a reasonable market for PV within the country.

(4) Single crystal or polycrystalline wafers or sheets could be imported and fabricated locally into solar cells and assembled into modules. A higher level of investment, technical expertise and infrastructure is necessary for this option. The danger of technological obsolescence of simple or lower TT does exist, since PV technology is still in the developmental stage. The return on capital investment demands a market of a few MW_p per annum for these products, which could exist only if the Gambia became the sole supplier to the North-West African sub-region.

(5) Purified silicon feedstock material could be purchased as single crystal or polycrystalline silicon ingots or sheets grown from it. The local PV system manufacturing industry therefore includes all the stages from ingot or sheet crystal growth to module assembly to PV system design and installation. Although a very high capital investment is needed for this, the potential exists for supplying EG-Si to the semiconductor industry as well as to the local PV industry. This approach is suitable if a large potential demand for PV energy technologies exist locally and in the North-West African sub-region.

(6) The last option, requiring the highest level of capital investment, offers the greatest security in terms of uncertainties in supply of either purified silicon feedstock material or silicon wafers or sheets from PV

system manufacturing countries. Greater economic viability of the PV industry exists here because of the possibility of supplying EG-Si both to the larger semiconductor industry and to the PV industry. Export potential to other countries also exists for any of the products from the various stages of PV manufacture. However, the scale of investment is so large that markets for millions of wafers per year would be essential, and this is not a near-term prospect.

TABLE 8.1 COMPONENTS OF PV MANUFACTURING TECHNOLOGY.

- PV Technology
  - PV Array Technology
    - Reduction to Si & purification
    - Crystallization to wafer/sheet form
    - Device Fabrication
    - Module Assembly
  - BOS Technology
    - Array BOS (Array structure, module network)
    - Nonarray BOS (High efficiency components, power control unit)

TABLE 8.2 COMPONENTS OF PV MANUFACTURING TECHNOLOGY AND THE LEVELS OF TECHNOLOGICAL COMPLEXITY.

- Reduction to Si and Purification
  - Trichlorosilane Process (Siemens)
  - Silane Process (Union Carbide)
  - Silicon Fluoride Process (Motorola)
- Crystallization to wafer/sheet form
  - Single crystal or polycrystalline ingots - slicing into wafers
  - Single crystal, poly-Si or a-Si sheets/ribbons
- Device fabrication
  - Junction formation
    - Thermal diffusion
    - Ion implantation
  - Contact formation
    - Vacuum vaporization
    - Screen printing
    - Plating
  - Lapping
  - Polishing
  - Antireflective coating
- Module assembly
  - Cell stringing
  - Module encapsulation
    - Silicon pottant
    - Vacuum lamination

8.3 A PV PROGRAMME FOR THE GAMBIA.

The piecemeal programme of PV installation which the Gambia has experienced so far has nevertheless shown clearly the value which could be derived from a concerted action to make PV widely available. The potential applications can be divided into two categories, the first being a commercial market for lighting, battery charging etc, the second being sales to communities or institutions for water pumping, health care, communications, education and grid-support. A block diagram of the potential PV applications is illustrated in figure 8.5.

8.3.1 LIGHTING FOR DOMESTIC AND COMMERCIAL USES

The provision of lighting to ordinary Gambians is a social service for economic development, increasing the length of their productive working day and countering population drift from villages to cities. PV lighting units could be installed as single or multiple lamps, powered from a single array. The PV array charges a battery which in turn powers a low voltage, efficient DC lamp. The reliability is high and this is a very attractive option compared to kerosene lamps or diesel powered lighting [161][80].

Kerosene lamps are the most common lighting unit in the rural areas but give poor light, are a fire hazard and can take a significant fraction of the cash income of a poor family. On a life cycle cost basis, PV lighting has been shown to be cheaper than that from a kerosene or

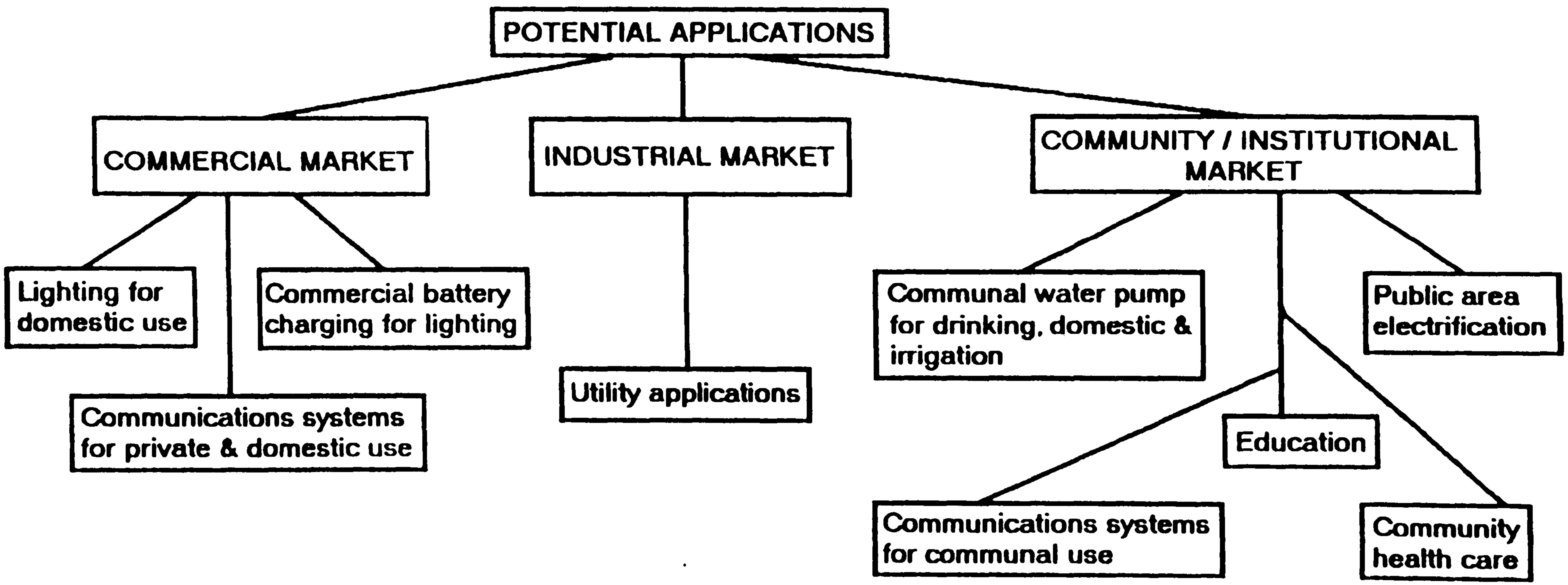


Figure 8.5 Potential PV applications in the Gambia.

hurricane lamp [76][162], but neither householders nor small traders evaluate products on that basis. Their concern is with initial capital cost and the quality of the light. Where the light intensity is important, as with a small shop, factory, school, health centre or office, then PV lighting is greatly preferred and the difference in capital cost can be justified. For domestic uses, it may be necessary to organise a financial package which allows a householder to purchase a PV system and spread the repayments. There is a wide range of potential customers having different requirements, from domestic use in homes through to commercial usage in shops and offices.

8.3.2 WATER PUMPING.

The provision of clean drinking water is the most important application for PV pumps. Impure drinking water is responsible for a large fraction of the illness and infant mortality in many developing countries. The provision of adequate supplies of clean drinking water is a major social benefit.

Another major importance of solar water pumps is for irrigation of crops. The Gambia, being part of the Sahelian drought-stricken region, has experienced a drop in crop yields, mainly because of reduced availability of water for crops. The expansion and increase of food supplies is a major concern to all Gambians.

In most cases, PV pumps are provided to villages or communities for drinking and domestic uses. Individual farmers should be encouraged to purchase these systems for irrigation via an attractive financial route for repayment.

8.3.3 MEDICAL USE.

The provision of health care in rural and some urban areas is a major task in most developing countries and is seriously hindered by the absence of energy supplies. In the Gambia, the medical and health department runs an immunisation programme with assistance from the World Health Organisation (WHO). The success of this immunisation programme depends on the maintenance of the cold chain for vaccines, which must be kept at temperatures between 0 and 8°C from manufacture to injection if they are to be effective. PV powered refrigerators are needed at some of these health centres as part of the cold chain.

Emergency standby batteries in hospital operation theatres are continuously being charged by PV systems and some sterilising units are also PV operated. An aspect of rural health care which is often overlooked is the need to attract and retain skilled staff, who could easily find work in towns or cities. Their quality of life can be greatly enhanced by the provision of a small PV system for powering lamps, fans, music centre, TV, video, etc, helping to bring an improved standard of care to the rural areas. This improved standard of health care needs to be expanded to cover the whole country so that reliable health care is available to all the people.

8.3.4 COMMUNICATION SYSTEMS.

Development efforts are greatly enhanced by improvements in communication systems within the country and with the outside world. In the Gambia, most of the telephone networks in the rural areas are PV powered. They require little power, but reliability is often of paramount importance. Some other communications uses include TV, the recharging of batteries for radios, radio transceivers for aid workers, health centres, etc., and navigational aids.

The Gambia Civil Aviation Authority operate and maintain diesel generators at remote site. The operating cost of these generators is very high. The economic benefits in replacing these generators with PV or PV/hybrid systems is very good.

8.3.5 RURAL ELECTRIFICATION.

Village electrification is a priority in most developing countries, on the grounds of social equity, economic development and countering population drift from village to city. There is significant benefit to the national economy in reduced dependence on imported oil products by using naturally available sunlight in electrifying the rural areas. The provision of lighting systems would enable villagers to perform extra productive work after dusk, since during the day they are busy on the farm.

8.3.5.1 PV Solar Home Kits.

Supplying electric power to most of the rural areas in the Gambia by the conventional grid method would be almost an impossible task at huge cost. Some of these communities need only small amounts of power. The use of stand-alone PV solar home kits is an appropriate means of supplying the minimum amount of electricity to most rural household [163]. Samples of PV solar lighting kits are shown in figures 8.6, 8.7 and 8.8. Their use eliminates the high investment required to connect the potential consumers to the power grid.

An example of a cost-effective means of providing energy services to rural inhabitants comes from the "PRONASOL" programme in Mexico, run by the national electricity utility [164]. The national electricity utility supplies PV solar home kits to individual households in villages and in return each household pays a fixed monthly sum. The utility has personnel that visit each village, describing the benefits, limitations, costs and giving basic training on the effective use of the PV system. In most cases where PV is more cost-effective, this programme could be emulated in the Gambia.

The PV systems are obtained from supplies by offering contracts through tender. The contracts include hardware, installation and the establishment of a local spares and maintenance base for at least five years. The utility has a quality control system, which not only checks the suitability of the PV system on offer, but visits each village to check on the installation of the

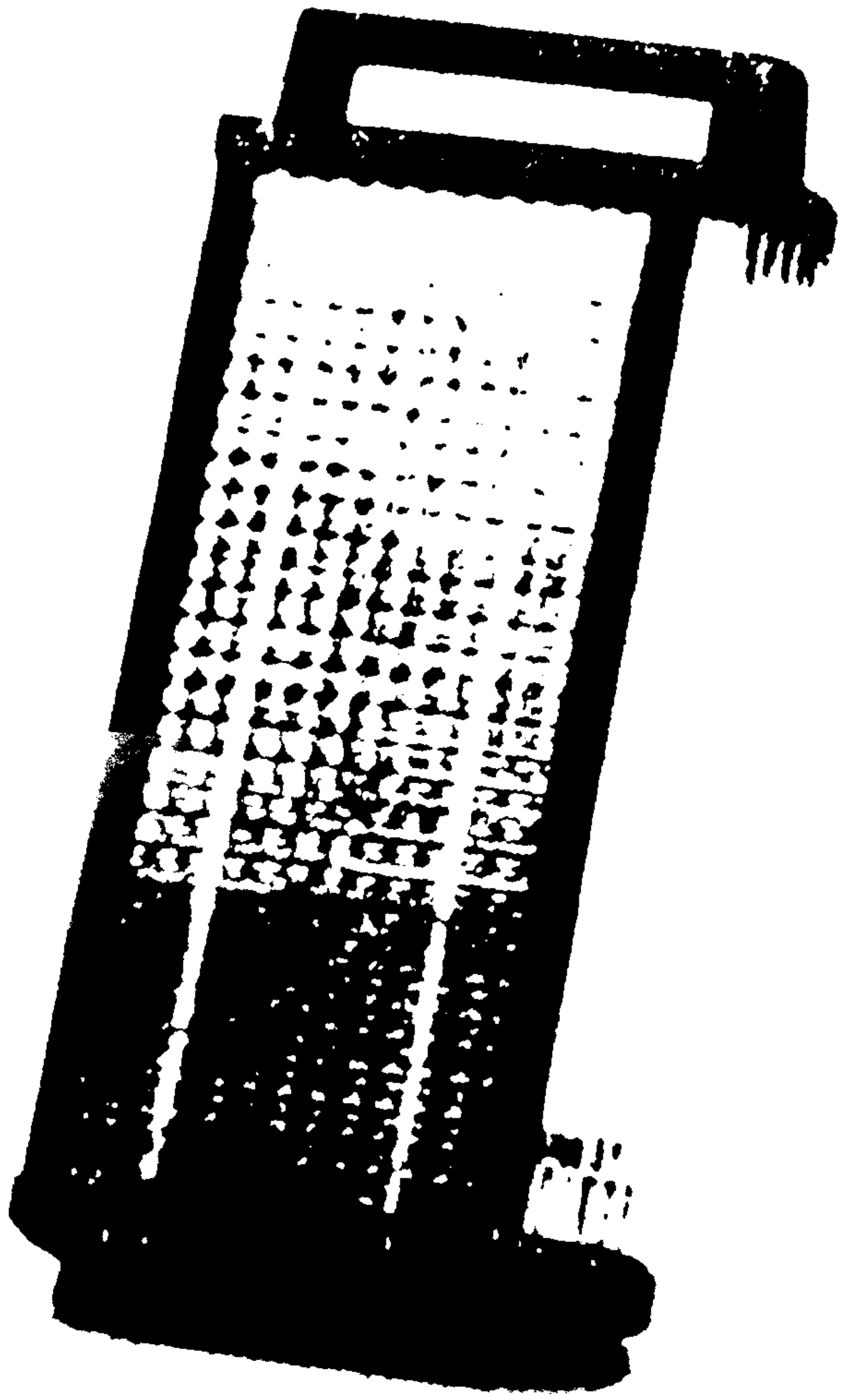


Figure 8.6 Self-contained PV lantern [165]

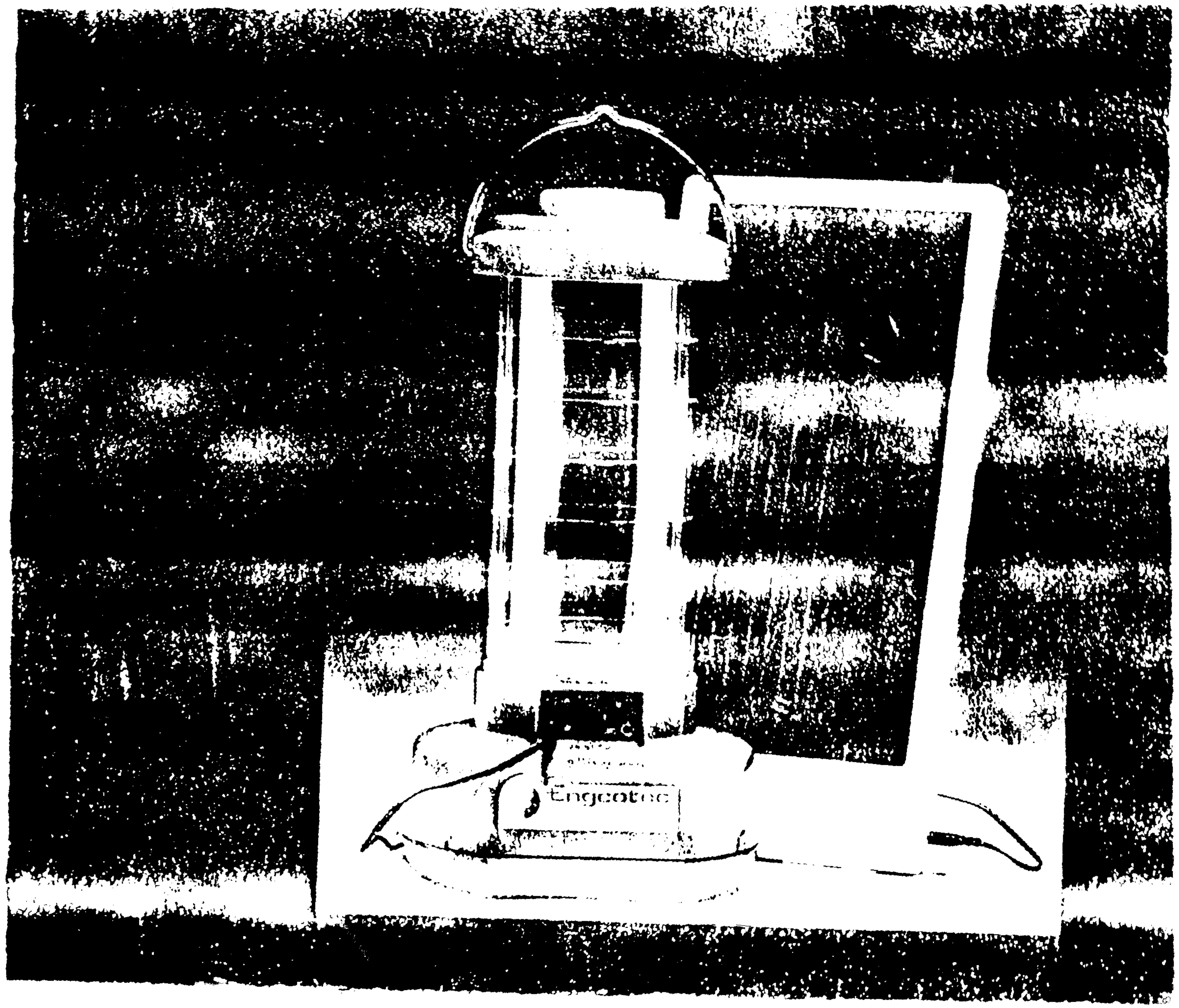


Figure 8.7 Plug-in PV lantern [166]

Figure 8.8 Fixed PV array lighting system [167]

systems with annual follow-up visits to check on the performance of the systems and the maintenance arrangements and to obtain feedback on the satisfaction of the villagers.

8.3.6 EDUCATIONAL USE.

Education is the key to social and economic development in all countries. Developing countries experience severe problems due to the high ratio of pupils to trained teachers, particularly in the rural areas. PV powered TV and videos sets, radios, computers etc, can make a significant audio-visual impact on the learning abilities of students while boosting the confidence of teachers and exposing the students to high quality teaching. These systems were first installed in French speaking African countries and schemes have been promoted in a number of other countries, most notably in India where a satellite TV service is operated. Adequate teaching of many aspects of a school's syllabus is possible only if a supply of energy is available. Some science experiments can only be demonstrated with the aid of electricity and such small amounts of power can make a dramatic difference to the understanding of the natural world for children in rural areas.

Many rural schools in the provinces are neither grid connected nor have access to electricity supply and this situation affects thousands of school children. Adult education is another area where PV can make a significant contribution since most adult education classes are held at night. PV fluorescent lights give out good quality light saving a strain on the eyesight. These classes are expanding with recorded intakes of several hundreds in some areas.

There is a continuing need for education in family planning methods, child care, farming methods, disease control and prevention etc. A video or slide presentation can have much more impact than a lecture and the message can be put across with much more force.

8.3.7 UTILITY APPLICATIONS.

Around the urban areas from Banjul to Brikama, the demand for electricity is high and the electricity utility, MSG, is unable to meet the demand. This results in load shedding and voltage fluctuations with considerable disruption to industry, commerce and private individuals, involving quite a high financial burden.

To meet these rapidly growing demands, there is a good opportunity to install PV systems of about 1 MW size in selected locations on the distribution grid and individual buildings of large industrial users such as hotels. This is likely to be a cheaper way of upgrading the service to customers than increasing the diesel generating capacity and renewing the gridlines, transformers and switchgears. The proposed hybrid system will allow power to be fed to customers by the PV network during the availability of sunlight and by the diesel generators during the non-sunshine periods. This system will not only increase the lifespan of the diesel generators at Kotu but will also drastically reduce expenses and make enormous savings on fuel, spare parts, maintenance/servicing and manpower, whilst improving the quality of power and reliability of services to the customers.

Large industrial energy consumers (like the Gambia Ports Authority, Gambia Produce Marketing Board, Gambia Telecommunications Company, Gambia Civil Aviation Authority, etc.) could be encouraged to supplement their energy needs with PV. Most of their energy demand take place between 9AM and 4PM when there is plenty of solar radiation, hence reducing the need for an expensive storage system and making the use of PV even more cost-effective.

8.4 PV AWARENESS PROGRAMME.

In order to gain the confidence of potential users and, hence, achieve widespread dissemination, there is a need for well organised PV demonstration programmes. These demonstration programmes not only give users and potential users an insight into the operation of the PV system but also gives manufacturers and distributors valuable experience of system performance in the field.

The evaluation of these pilot-projects has led to much improved reliability of the PV systems, a clear idea of their cost-effectiveness and also an understanding of the part to be played by the recipients [168].

8.4.1 AFTER SALES SERVICES.

The PV companies or PV technology transmitters must provide systems that works as efficiently as possible in the local conditions and must arrange for their long term reliable operation [169]. Accurate sizing and design for reliable operation, the provision of training to local personnel in operation and maintenance and the development of means for supply of spares and repair of faults are essential.

Training should be included in the contract for the supply and installation of PV systems and locally trained personnel paid as part of the contract. Also to be included in the contract is the supply of spare parts, repairs and/or replacement of faulty components.

8.5 USER'S PARTICIPATION.

Although the Gambia government will be expected to play an important role in facilitating the importation of PV systems and the selection of sites, those whom the PV system is intended to benefit must be involved in the decision to accept the system and be sufficiently convinced of its benefits that they will agree to contribute to the capital costs. The government or Non Governmental Organisation (NGO) must set up selection mechanisms in conjunction with any donor agency involved with the funding of the programme. They will have to put in place a mechanism for collecting payments from the users, adopt proper accounting and auditing procedures and use the funds for their intended purpose.

In the urban areas, where there are existing banking structures, these can take on the responsibilities of collection and disbursement of payments. In the rural areas, where there are mainly cooperative groups, this role could be incorporated into their activities [170].

In most cases where the governmental or donor agencies cannot pledge or provide long term financial support for operation and maintenance, the people enjoying the benefits of the energy services should be willing to pay for the future costs of operation and maintenance [171]. This is to ensure that the PV module with a life span of about 25 years is utilized to its full potential.

8.6 INFRA-STRUCTURAL NEEDS.

If the Gambia is to embark on a coordinated programme to exploit PV wherever it is cost-effective to do so, then there must be an infra-structure established to support that programme. There are three aspects to the infrastructural needs - the organisational aspect, the supply and maintenance of the PV systems and the provision of financing for the purchase of the systems. A block diagram of the infra-structural needs is illustrated in figure 8.9.

8.6.1 ORGANISATIONAL ASPECT.

For the Gambia, innovative efforts will need state planning and organisation. This is mainly to do with research, development, production and marketing of PV

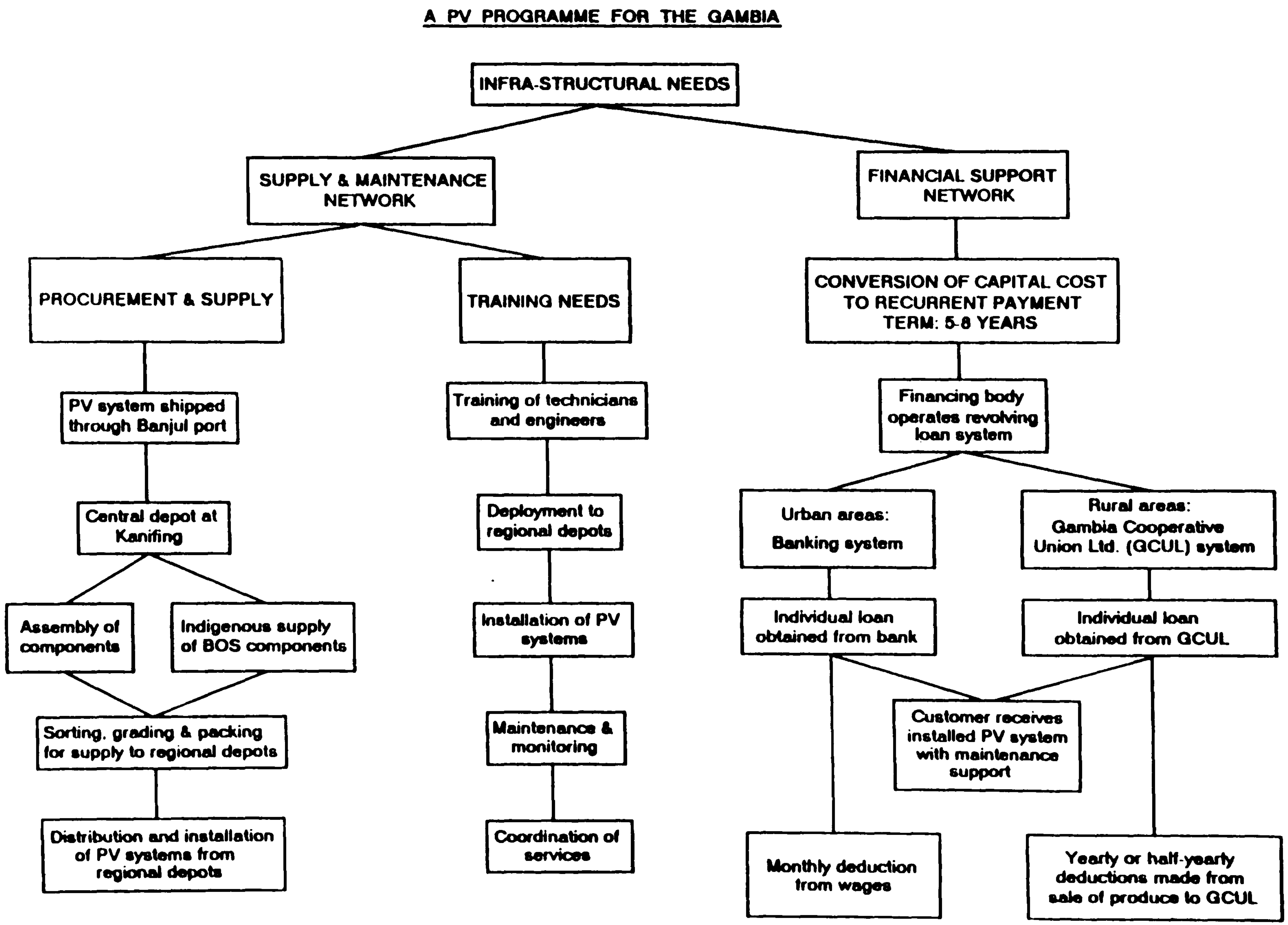


Figure 8.9 Infrastructural needs of the PV programme for the Gambia.

systems. The improvement and adaptation of indigenous or imported technology and increased efficiency of resources deserve close attention. Because of shortage of capital and other factors, the PV market in the Gambia will demand an initial small scale of operation and then nurtured to grow. Hence the technologies needed initially are those appropriate to small markets e.g. the assembling of PV modules and the manufacturing and assembling of balance-of-systems (BOS). Initially, the market might not be large enough to warrant investment in the types of plants to which international investors are generally accustomed in industrial countries. However, with sharper vision and refined mechanisms for conducting the search, opportunities could be found to supply small markets, using technologies of a type that are suitable.

The government could decide through a non-commercial model of TT, to request technical assistance through a bilateral agreement for organisational framework in setting-up the PV technology industry. There should be provision for education and training of Gambians to manage the industry. The exchange of information at international conferences, trade fairs, etc and the acquisition of information from books, journals and other publications should also follow.

8.6.2 SUPPLY AND MAINTENANCE.

The capital city, Banjul, is also the main port of entry into the Gambia and the PV modules and systems would be shipped into Banjul. The Kanifing industrial area could be the location for a central depot for the network with some of the local companies encouraged to supply some system components. This indigenous fraction would increase in time as local firms became familiar with PV technology.

The first phase of the PV programme would need to concentrate marketing largely on the urban areas from Banjul to Brikama. Within this area are about 100,000 householders who are potential customers for PV systems, whilst the banking network is established in this area, transport is not difficult and supply and maintenance could be organised without too much difficulty. It is in this area that embedded and distributed utility generation would be most useful and economically attractive and studies for MSG would establish the optimum size and location of such systems. During this phase, the institutional markets for medical uses, education and communications would also be established, via the central supply depot in Kanifing.

Associated with the first phase must be a training programme. The Gambia Technical and Training Institute (GTTI) is located at Kanifing and would be the obvious choice for the main training programme, in association with the Gambia Renewable Energy Centre, located on the same premises.

Once the first phase is being successfully implemented, the second phase could begin to extend the coverage to the entire country. In this phase, the potential purchasers are the rural population whose main needs are for battery charging (for radios etc.), lighting, and water pumping. Battery chargers and lighting systems could be installed either as a utility programme with customers renting the PV systems, as in the Mexican programme [172], or could be purchased by individual householders or small shopkeepers. There is also a communal need for clean drinking water, most suitably provided by PV pumps and, by some farmers, for irrigation which might also use PV pumps.

The supply and maintenance network will need to be extended in this phase to secondary depots in the larger towns in these areas, and associated training courses could be given at regional centres such as the Anglican Training Centre at Farafenni. Transport is more difficult in the rural areas, but maintenance cover should be eased by the reliable telephone system being brought about by the use of PV by GAMTEL to power their telephones.

8.6.3 FINANCING.

The Gambia is not a producer of fossil fuels and must at present import all its fuel. Lovejoy [173] has shown that the use of PV as a replacement for diesel engines can result in a significant saving of foreign currency and so has considerable macroeconomic benefits for countries such as the Gambia. It is therefore sensible for the Government to make arrangements which will assist the promotion of PV and it is a very appropriate target for development aid.

The customs duty and sales tax of 30.9% and 10% respectively makes PV expensive and are serious potential deterrents to a lot of Gambians. There is an urgent need for the government to consider removing or substantially reducing these taxes on PV. This substantial reduction in taxation could be seen by the government as a short term loss of revenue but, in the long term, they would gain from savings on reduced importation of fuel and increased economic activities.

At the microeconomic level, there is a need for most potential purchasers to convert the capital cost of PV systems into a recurrent payment spread over some years. In the urban areas, the banking network can be used by individuals, although the rate of interest on personal loans (about 25% p.a.) would make a PV system very expensive. There is a need to organise low interest loans, with rates comparable to the 9% p.a. paid by Government servants. This could be done as part of an externally funded revolving loan package or by a Government decision to support the purchase of PV systems in order to reduce the national outflow of foreign currency.

Farmers in rural areas sell their produce through the Gambia Cooperative Union Ltd. (GCUL) and this organisation could purchase PV systems for the farmers and take payment for the system out of the reimbursement for the produce sold to GCUL.

8.7 COMMERCIALISATION OF THE PV MARKET.

Studies undertaken by the World Bank [174], UNESCO [175] and USAID [176] have shown that PV is the optimum means of generating electricity in developing countries in many cases, from the point of view of both cost and reliability. There are quite a number of PV applications in the Gambia that are cost-effective on a life cycle cost basis and commercially viable, provided financial schemes are made available [76]. For the commercial market to receive a boost, it needs a financial scheme that will allow individuals to purchase PV systems and then spread the repayments.

8.7.1 POTENTIAL SYSTEM PURCHASERS.

The population in rural areas of developing countries is collectively very large, but also has little access to capital. It is only recently that serious studies have been made of the routes by which the urgent needs of this high potential market might be satisfied. In order to ensure a flourishing market there is a need to perform a market survey of potential customers. From this survey, the needs and financial viability of the market can be established.

8.7.1.1 Individuals.

In general, users are buying a small system to provide a needed service and they have requirements which go beyond the lowest financial cost of that service. These include compatibility and ease of introduction of the technology. The financial comparisons of this purchasing group are largely determined by government policy on such matters as fuel subsidies, interest rates, capital availability etc. Thus, the market can be encouraged or stifled by government action.

Individual farmers who can afford to purchase these systems for irrigation, lighting, etc., should be encouraged by information on the life cycle cost benefits and by persuasive demonstration in their own locality. It should be noted that each kind of potential purchaser views the costs and benefits of PV systems from a different viewpoint.

Failure of the system may have dire consequences for the individual user in a developing country, leading to a reluctance to adopt a technology which has not been proven effective in the user's locality.

8.7.1.2 Cooperative Groups.

Farmers in rural areas sell their produce through the Gambia Cooperative Union Limited (GCUL) and this organisation could purchase PV systems for the farmers and take payment for the system out of the reimbursement for the produce sold to GCUL. In the urban areas, the banking network can be used by individuals, although the rate of interest on personal loans (about 25% p.a.) would make a PV system very expensive. There is a need to organise low interest loans with rates comparable to the 9% p.a. paid by government civil servants. This could be done by the PV companies as a marketing strategy to make their products available to as many Gambians as possible or by government decision to support the purchase of PV systems in order to reduce the national outflow of foreign currency.

8.7.1.3 Non-Governmental Organisation (NGO).

These bodies are often both the purchaser and the user of the PV system. They will choose to purchase a PV system if the system has the lowest relative cost, where that cost is measured in terms of capital, operating and organisational costs, but may also include the time and effort involved in introducing a new technology. Failure of the system would be of immediate effect in terms of lost revenue to the purchaser and, thus, reliability is often of equal importance to capital costs.

8.7.1.4 Government Institutions.

For large installations or a large number of small installations, the purchaser is usually a government department or government sponsored agency. In this case, the purchasing body is very rarely the end user of the system. The main criterion for purchase is that the photovoltaic system can provide a needed service at a lower overall financial cost than alternatively powered systems. In some cases, political considerations such as availability, either at the time of purchase or in the future, social development plans etc., may also affect the decision to purchase. In general, financial assistance to allow the capital cost to be spread over the system lifetime will be available. Failure of the PV system may be an embarrassment to the government department in question, but a potentially more serious consequence is that of rejection of PV as a future option. It may be that the reliability of the product is of considerably more importance to both the user and the supplier than to the purchaser.

8.7.2 PV CONSUMER PRODUCTS.

There are lots of examples all around the world where commercial approach to PV dissemination has been adopted. Some examples of PV powered consumer products are:- calculators, watches, clocks, torch-lights, etc. Commercial markets in developing countries occur mainly in those countries with growing economies, where a significant number of people have a monetary income larger than that needed for essentials, but have no access to a reliable source of electricity. These people are not only the urban elite, but include small shopkeepers, farmers and many others within a growing monetary economy.

8.7.3 ESTABLISHMENT OF "PRODUCT CHAMPIONS".

It has been observed that the promotion of PV in many countries have been very effective through knowledgeable, enthusiastic and influential people, commonly known as "product champions" [169]. They will promote PV as a technology appropriate to the needs of their country. The importance of a "product champion" in the initial stages of a PV programme is very vital. Also vitally important are entrepreneurs who devote a lot of their resources in setting up PV commercial ventures and ensuring that these ventures are nurtured to maturity.

8.7.4 THE ROLE OF DONOR AGENCIES.

The availability of funds from abroad has been important in the establishment of credit facilities for potential customers and in providing capital for production facilities. It is also clear that the inappropriate use of overseas aid can seriously damage the indigenous industry and aid agencies must be very careful in their selection and design of projects to support and expand local industries and not injure them.

Another important role in catalysing the development of a commercial market is through purchases by charities and NGO's. These institutions have a very good track record of providing continuing support to villagers and rural people and in implementing development projects which are sustainable. They also provide better working conditions for their field workers as compared to government civil servants.

8.8 PV TECHNOLOGY TRANSFER.

The dissemination of PV in the Gambia is a form of technology transfer. The transfer can be a direct one, where the PV system is supplied directly from the PV company to a village in the rural areas, or indirect, through intermediaries. The roles and responsibilities of the transmitter (transferor) and receiver (transferee) of the technology need to be carefully thought through if the project is to be successful.

A commercial model of TT for the Gambia could offer a long term viability of the PV industry. Appropriate government intervention is needed through a non-commercial model of TT in setting up the basic infrastructures for PV technology, i.e. education, training, provision of technical assistance, etc.

8.8.1 ROLES OF TRANSFEROR AND TRANSFEREE.

The transfer of technology is a transaction between at least two parties, the transferor and the transferee. Both parties must be able to meet the essential needs of the other in order for the transfer to be successful. The transferor must be able to deliver the technology that meets the needs and expectations of the transferee. This is achievable by the transferor demonstrating and describing exactly the functions and limitations of the technology. This will give the transferor the opportunity to obtain potential transferees, since their needs and expectations are to be met by this technology. Alternatively, transferors can survey the needs and expectations of potential transferees and develop technologies specifically designed for them. It is expected that the transferee is in a position to accept the technology and use it to its full potential.

8.8.2 LEVEL OF TECHNOLOGY TRANSFER.

The technology transfer for the Gambia will mainly depend on its technical, industrial and intellectual capabilities. Currently there will be a need to import PV modules and then later cells could be assembled into modules. Most of the balance-of-system (BOS) will have to be imported but some system components could be assembled in the Gambia. These included BOS items like charge controllers and regulators, inverters and batteries. The possibility of exporting or re-exporting these BOS to the West African sub-region could be investigated.

8.9 CONCLUSION.

PV is a reliable and cost-effective alternative form of energy for many applications in the Gambia and as a source of social and economic development. In order for the nation to realise fully the benefits of PV, individuals must be encouraged to purchase PV systems by giving financial assistance which transforms the capital payment into a recurrent payment over the lifetime of the system.

Since PV helps to supplement the energy needs of the nation, it reduces the dependence on imported fuel for electricity generation, with consequent savings in foreign currency. A gradual change from conventional fuels to PV would benefit both the economy and the nation as a whole. However, in order to reap the benefits, there is a need to encourage purchase of all PV systems free of customs duty and sales tax. At present, the duty on PV systems is 30.9%, with an additional sales tax of 10%. This taxation makes the system too expensive for most Gambians and discourages the potential purchaser from acquiring the system. However, if these taxes were removed or substantially reduced, it is likely that the economic benefits from the use of PV in terms of reduced importation of fuel would be greater than the loss of tax revenues.

For a successful PV market to flourish in the Gambia, there is a need for a properly coordinated training programme and enhanced national investment capability development. This embraces interventions in education and training, the physical and technological infrastructures and the development of supporting institutions.

It is essential to have a few influential personnel that are willing and able to promote the use of PV and secure the organisational structures needed to facilitate its use.

Part of the dissemination of PV in the Gambia involves a form of technology transfer, where both the transferor and transferee play an active role in meeting the needs and expectations of each other. A vital part in encouraging the usage of PV is through demonstration programmes. These are very often viewed as demonstrations of the technology, but to be successful they must also take account of the needs of the end user and must contribute to building a capability to make good use of PV in the Gambia.

Six stages of acquiring the PV technology have been identified and the Gambia could enter the PV manufacturing industry at any stage via appropriate models of technology transfer. Stage two has been recommended for the Gambia, where PV modules are imported, more efficient BOS manufactured in the Gambia, and the design and integration of the complete system done by local expertise. The next stage would be to assemble solar cells into modules and so on, provided there is increased demand and greater activity in the PV market.

CHAPTER 9

9.0 SUMMARY AND CONCLUSION.

It is overwhelmingly clear that a developing country like the Gambia cannot afford to spend most of its meagre resources on the importation of fuel. The Gambia has very few natural energy resources except that of solar energy which it has in abundance. This has highlighted the need for a coordinated programme to exploit this indigenous resource where it is cost-effective for socio-economic development.

The objective of this research programme has been to study the options for the use of renewable energy sources in the Gambia and to identify those sectors where PV could play a role in the social and economic development of the country. The provision of energy services and their role in promoting development, and the present and possible future means of providing these services have been studied to provide a context for the discussions on the potential roles of PV. A number of renewable energy technologies could be of great benefit to the Gambia, meeting existing needs more cost-effectively or meeting needs presently unfulfilled. Within the renewable sources, PV has a particularly important role in providing electricity for areas off-grid. Therefore the research programme included a study of the means of transferring PV technologies into the country and the steps needed for the Gambia to make best use of PV.

In chapter two, it has been shown that energy consumption in the Gambia must continue to grow if development is to proceed and if poverty and deprivation are to be alleviated. It is equally evident that traditional and conventional approaches to energy supply have a limited future and need to be re-evaluated to ensure short term survival and establish long term energy viability. This situation has highlighted the need for an integrated energy plan. The Gambia's energy demand is heavily weighted towards fuelwood and the rate of consumption is greater than the rate of sustainable yield. There is an urgent need to address the energy demand by making greater use of renewables, increasing the reforestation rate, and conserving and using energy more efficiently. Part of the Gambia's development progress will require the availability of proper and adequate energy.

In chapter three, the Gambia's energy balance has been assessed from the end-use energy approach. The energy demand pattern and some areas which require better energy services have been identified. A method of reducing the fuelwood consumption is by switching to more efficient use of alternate sources of energy. Substantial savings in energy could be realised by using more energy efficient appliances. The Gambia's generation and distribution of electricity involves high energy losses. There is a need to conserve energy in this area of the energy balance. The Gambia's energy demand for fossil fuels is on the increase. This trend could be reversed by the efficient use of renewables to provide more cost-effective services. There are sectors in which renewables could provide more efficient and cost-effective services.

In chapter four, the roles of some renewable sources of energy for the Gambia have been described. These renewables could help reduce the Gambia's energy balance being too dependent on conventional fuels. The appropriate sources of energy looked at are as follows:-

(1) Trees as a source of fuelwood.

(2) Energy crops for conversion into different types of fuel.

(3) Agricultural/Organic wastes to be used as fuel for cooking and heating.

(4) Peat as a promising energy source.

(5) Biofuels in the form of biogas, alcohol fuels and vegetable oils mainly to power engines.

(6) Draught animal power mainly for agricultural and transportation purposes.

(7) Ocean/Hydropower for generation of electricity

(8) Wind power for water pumping.

(9) Solar energy for both passive and active generation of energy.

In chapter five, the techno-economic benefits of some PV applications in the Gambia were assessed for lighting, water pumping and medical vaccine refrigeration. The techno-economic and reliability analysis of a PV lighting system compared to a conventional kerosene hurricane lighting system indicated that PV lighting system was more cost-effective and of a superior standard. Its benefits are overwhelming. Unfortunately, individuals do not evaluate products on this basis, with their main concern being on initial capital cost even though they will have to pay a lot more on a life cycle cost basis. The feasibility, viability and prospects of this PV lighting system is quite good for the Gambian situation if a system of financing can be established. The economic viability of PV water pumping compared to the conventional hand-pumping mainly depends on the quantity of water needed and the head size. It has been observed that it is more economical to use handpumps for lower quantity and head size, but, for larger water quantity or head size, PV pumps are more favourable. There is a crossover point, where both systems are equally favourable and this point varies with variation in economic or technical parameters. Although a kerosene refrigerator has a lower annualised life cycle cost than that of a PV refrigerator, the reliability and availability factor of PV is higher hence making the annualised life cycle cost per potent vaccine dose lower. There is a need to arrange credit facilities in order to encourage more Gambians to use the cost-effective PV systems.

In chapter six, an economic case study of PV, diesel and PV/diesel hybrid systems for powering telecommunications and navigational aids at Banjul International Airport have been analysed. The equipment at Koloro, which is owned and operated by the Gambia Civil Aviation Authority, can be powered with a PV/diesel hybrid system much more cost-effectively with higher reliability than diesel generators or PV stand-alone.

In chapter seven, different models of technology transfer to developing countries have been discussed and an assessment made of the needs and associated problems for developing countries and the Gambia in particular. The appropriate models and strategy for PV manufacture and dissemination in the Gambia have been identified as well as the means of transferring these technologies to obtain an endogenous capability. The technology transfer must be made in an appropriate economic environment in which the necessary infrastructures are in place, needed supplies are available, and market and profitability perspectives are adequate. With the importation of an appropriate technology, it is essential that the local work force obtain the training and skills necessary to operate and develop further the ability to produce new technologies leading to eventual self-reliance.

In chapter eight, an assessment of the relevant criteria for the Gambia to acquire the PV technology was carried out. Several levels of acquiring the PV technology through technology transfer were identified. The second level of the PV technology transfer stage was recommended for the Gambia. The present situation in the Gambia requires PV modules to be imported, more efficient balance-of-system equipment manufactured, and the design and integration of the complete system to be done by local expertise. Progress to the third level of the PV technology transfer stage should only be attempted when there is increased demand, greater economic activity in the PV market and the acquisition of technological mastery is achieved. A gradual change from conventional fuel to PV, where it has been found to be cost-effective, would benefit both the economy and the nation as a whole. This has highlighted the need for PV tax incentives and financial assistance in enabling the majority of Gambians to obtain a PV system. A successful PV programme has to be properly coordinated, embracing interventions in education, training and development of supporting institutions.

On completion of the Ph.D. programme and subsequent return to the Gambia, the knowledge gained will be used in the installation, testing, monitoring and commissioning of the first PV powered navigational aids and communication system at Banjul International Airport, in collaboration with IT Power and Newcastle Photovoltaics Applications Centre.

REFERENCES.

[1] "Energy, Environment & Development in Africa: Opportunities and constraints", Eds. Phil O'Keefe, Paul Raskin and Steve Bernow, The Beijer Institute Publications, Stockholm, Sweden, 1984.

[2] B.K. Kaale, "Five year plan for village Afforestation", Dar es Salaam: Tanzanian Forestry and Beekeeping Division, Ministry of Lands, Natural Resources and Tourism, 1983.

[3] I. Kikula et al, "Village afforestation in Tanzania", Report to the Institute of Resource Assessment, University of Dar es Salaam, 1983.

[4] The Gambia Consumer Price Index - 1993, The Gambia Central Statistics Department, Ministry of Finance & Economic Affairs.

[5] The population & Housing Census 1993, Provisional Report-1, Central Statistics Department, Ministry of Finance & Economic Affairs, June 1993.

[6] Richard H. Hosier, Mark J. Mwandosya and Matthew L. Luhanga, "Future energy development in Tanzania", Energy Policy, May 1993, pp524-542.

[7] Johannes F. Linn, "The cost of urbanization in developing countries", Economic Development and Cultural Change, Vol 20, No 3, 1982, pp625-648.

[8] Paul Bairoch, "Cities and Economic Development: From the Dawn of History to the Present", translated by Christopher Braider, University of Chicago, IL, 1988.

[9] Jeffrey Williamson, "Migration and urbanization", in H. Chenery and T.N. Srinivasan, eds., Handbook of Development Economics, Elsevier Science Publishers, New York, 1988.

[10] J. Darmstadter, J. Dunkerly and S. Alterman, "How Industrial Societies Use Energy", Johns Hopkins University Press, 1977.

[11] 1993/94 Budget Speech delivered by the Honourable Bakary Bunja Dabo, Gambian Minister of Finance & Economic Affairs in Parliament on 25th June 1993.

[12] Sam Moyo, Phil O'Keefe and Michael Sill, "The Southern African Environment", Earthscan Publications Limited, London, 1993.

[13] J. Goldemberg, "Basic needs and much more with 1KW per capital", Ambio, vol. 14 (1985): no.4-5 190-200.

[14] D. Schumacher, I. Berkovitch, R. Hesketh, J. Stammers, "Energy: Crisis or opportunity?", Macmillan Publication, UK, 1985.

[15] J. Goldbemberg, T.B. Johansson, A.K.N. Reddy, R.H. Williams, "Energy for a sustainable World", World Resources Institute Publications, USA, 1987.

[16] G. Foley, "The Energy Question", Penguin Books Publication, UK, 4th Edition, 1992.

[17] "Energy in the developing world, the real energy crisis", Eds. Vaclav Smil and William E. Knowland, Oxford University Press, New York, 1980.

[18] Michael Grubb, John Walker, et al., "Emerging Energy Technologies, Impacts & Policy Implications", Dartmouth Publishing Company Limited, U.K., 1992.

[19] 1993/94 Budget Speech delivered by the Honourable Bakary Bunja Dabo, Gambian Minister of Finance & Economic Affairs in Parliament on 25th June 1993.

[20] G. McInnes, "The Effectiveness of Policy Measures to Promote Energy Efficiency in Road Transport", Proc. Tomorrow's Clean & Fuel-Efficient Automobile: Opportunities for East-West Cooperation, Berlin, March 1991.

[21] James Mackenzie & Michael Walsh, "Driving Forces: Motor Vehicle Trends & Their Implications for Global Warming, Energy Strategies, and Transportation Planning", World Resources Institute, December 1990, Washington DC.

[22] "Energy, Environment and Development in Africa I", Edited by P. O'Keefe, P. Raskin and S. Bernow, Published by The Beijer Institute, The Royal Swedish Academy of Sciences, Stockholm Sweden, 1984.

[23] U. Able-Thomas, R. Hill & N.M. Pearsall, "A Model for PV Dissemination in The Gambia", Proc. 11th European PV Solar Energy Conference, Montreux, October 1992.

[24] Appropriate Technology, Intermediate Technology Publications, U.K, Vol.19, No.4, March 1993, .

[25] N.L. Brown, "Renewable Energy Resources and Rural Applications in the Developing World", Westview Press Publication, USA, 1978.

[26] D. Andersson & R. Fishwick, "Fuelwood Consumption & Deforestation in African Countries", World Bank Staff Working Papers No. 704, Washington D.C., USA, 1984.

[27] C.P. Mitchell, "Wood Energy for Local Use", In J. Twidell, "Energy for Rural and Island Communities", Conference Proceedings, Inverness, Scotland, September 1980.

[28] "Fuelwood Supplies in Developing Countries", Food & Agricultural Organisation (FAO) Forestry Paper No. 42, FAO, Rome, Italy, 1983.

[29] "Forests Trees & People", FAO Forestry Topics Report No. 2, FAO, Rome, Italy, 1985.

[30] L.A. Kristoferson and V. Bokalders, "Renewable Energy Technologies, Their Applications in Developing Countries", Intermediate Technology Publications, UK, 1991.

[31] "Agroforestry in the West African Sahel", National Academy of Sciences (NAS) Report, Washington D.C., USA, 1983.

[32] D.O. Hall, G.W. Barnard & P.A. Moss, "Biomass for Energy in the Developing Countries", Pergamon Press Limited, UK, 1982.

[33] L.P. White & H.G. Plaske, "Biomass as a Fuel", Academic Press, London, 1982.

[34] "Making Aquatic Weeds Useful", In "Some Perspectives for Developing Countries", NAS Report, Washington D.C., USA, 1976.

[35] G. Barnard & L. Kristoferson, "Agricultural Residues as a Fuel in the Third World", Earthscan Publications, London, UK, 1985.

[36] "The Gambia. Improving the production of fuel briquettes in Kaur plant and the use of agricultural waste products for fuel", United Nations Sahelian Office, Banjul, The Gambia, Project no. UNSO/DES/GAM/81/006, DANIDA, (1981).

[37] A. Kalmari, "Energy Use of Peat in the World and Possibilities in Developing Countries", Seminar on Peat, Bandung, Indonesia, June 1982.

[38] "Report on the Use of Peat for Energy", U.N. Conference on New and Renewable Sources of Energy, Nairobi, Kenya, 1981, (A/CONF.100/PC/32).

[39] "Report on the Use of Peat for Energy", UN Conference on New and Renewable Sources of Energy, Report No. A/CONF.100/PC/32, Nairobi 1981.

[40] G. Foley and G. Barnard, "Biomass Gasification in Developing Countries", Earthscan Publications, London, UK, 1983.

[41] John Twidell and Tony Weir, "Renewable Energy Resources", E.& F.N. Spon Ltd. Publications, London, 1986.

[42] I. Barwell & M. Ayre, "The Harnessing of Draught Animals", Intermediate Technology (IT) Publications Ltd., London, UK, 1982.

[43] "Draught Animal Power", In "Renewable Sources of Energy", Vol. V.ST/ESCAP/270, Economic & Social Commission for Asia and the Pacific (ESCAP), Bangkok, Thailand, 1983.

[44] "Animal Energy in Agriculture in Africa and Asia", Technical Papers Presented at the FAO Expert Consultation held in Rome, FAO, Rome, Italy, November 1982.

[45] Starkey, P.H., "Farming with Work Oxen in Sierra Leone", Sierra Leone Work Oxen Project, Njala University College, Private Mail Bag, Freetown, Sierra Leone, (1981).

[46] P. Garman, "Water Current Turbines: A Fieldworker's Guide", IT Publications, London, UK, 1986.

[47] P.G. Davis, et al., "Wave Energy. The Department of Energy's R&D Programme 1974-1983", ETSU Report R26, Energy Technology Support Unit (ETSU), Oxfordshire, UK, 1985.

[48] P. Fraenkel, et al., "Wind Technology Assessment Study", UNDP Project GLO/80/003, IT Power Ltd., Berks., UK, 1983.

[49] E.H. Lysen, "Introduction to Wind Energy", Consultancy Services Wind Energy Developing Countries (CWD), Amersfoort, The Netherlands, 1982.

[50] Intermediate Technology (IT) Power, Hants. RG27 OPR, UK, News Letter No.13, March 1994.

[51] B. Andersson, "Solar Water Heating in Developing Countries", Study prepared for the Swedish International Development Authority (SIDA), Stockholm, Sweden, 1984.

[52] D.A. Brainbridge, "The Integral Passive Solar Water Heater Book", The Passive Solar Institute, CA, USA, 1981.

[53] W.H. Grainger, et al., "Small-Scale Solar Crop Dryers for Tropical Village Use - Theory and Practical Experience", Appropriate Technology Group, University of Strathclyde, Glasgow, UK, 1981.

[54] C. Seufert, "Survey of Solar Cookers", German Appropriate Technology Exchange (GATE) GTZ, Eschborn, Germany, 1978.

[55] "Applications of Photovoltaics", Edited by R. Hill, Adam Hilger, IOP Publishing Ltd., Bristol, UK, 1989.

[56] U. Able-Thomas, R. Hill and N.M. Pearsall, "Marketing Strategies for PV Dissemination in The Gambia", Proc. 12th EC PV Solar Energy Conference, Amsterdam, April 1994.

[57] H.J. Hovel, "semiconductors and semimetals", vol.11, solar cells, New York, Academic Press, 1975.

[58] R. Hill, "Thin film solar cells in Active and passive thin film devices", edited T.J. Coutts, Academic Press Publications, London, 1978.

[59] D.M. Chapin, C.S. Fuller and G.L. Pearson, "A New Silicon p-n Junction Photocell for Converting Solar Radiation into Electrical Power", Journal of Applied Physics, 25, 676, (1954).

[60] M.A. Green, S.R. Wenham, J. Zhao, S Bowden, A.M. Milne, M Taouk and F. Zhang, "Present Status of Buried Contact Solar Cells", Proc. of IEEE PVSC, pp46-53, (1991).

[61] H.S. Ullal, K. Zweibel and T. Surek, "Recent Technological Advances in Thin Film Solar Cells", SERI/TP-211-3679, (1990).

[62] J. Hedestrom, H. Ohlsen, M. Bodegard, A. Kylner, L. Stolts, D. Hariskos, M. Ruckh and H.W. Schock, 23rd IEEE Photovoltaic Specialists Conf., Louisville, KY., 10 - 14 May (1993), p.364.

[63] M.L. Riston, J.C. Chen, M.S. Kuryla and H.F. Macmillan, "A High Yield Manufacturing Demonstration for High Efficiency GaAs Concentrator Solar Cells", Proc of IEEE PVSC, p128-132, (1991).

[64] A.L. Fahrenbruch and R.H. Bube, "Fundamental of Solar Cells", Academic Press, (1983), p317.

[65] J.P. Benner, "Cost Reduction Technology for High Efficiency Photovoltaics: Research Issues and Progress", Proc. of IEEE PVSC, pp7-11, (1991).

[66] M. Green and K. Emery, "Solar Cell Efficiency Tables", Prog. in Photovoltaics Research and Application, Vol 1, pp25, (1993).

[67] M.T. Bhatti, PhD Thesis, University of Northumbria at Newcastle, (1993).

[68] J.A. Bragaguolo, A.M. Barnett, J.E. Phillips, R.B. Hall A. Rothwarf and J.D. Meakin, "The Design and Fabrication of Thin-Film CdS/Cu_2S Cells of 9.15% Conversion Efficiency", IEEE Transactions on Electron Devices, ED-27, (1980), p.645.

[69] C. Ferekides, J. Britt, Y. Ma and L. Killian, "High Efficiency CdTe Solar Cells by Close Spaced Sublimation", Proc. 23rd IEEE Photovoltaic Specialists Conf., Louisville, KY., 10-14 May (1993), p.389-393.

[70] F.O. Adurodija, PhD Thesis, University of Northumbria at Newcastle, (1994).

[71] K. Eklund, J. Hedstrom, L. Stolt and P. Weissglass, 5th EUROCIS Contractor Meeting, Zurich 8-10 June, 1994, Published by AFIF Technopark ETH-Trakt, Pfingstweidstrasse 30, CH-8005 Zurich, Switzerland.

[72] M.C. Russell, "Residential photovoltaic system design handbook", DOE/ET/20279-255 (Concord: Massachusetts Institute of Technology, Northeast Residential Experiment Station, April 1984).

[73] F. Lasnier and T.G. Ang, "Photovoltaic Engineering Handbook", Adam Hilger Publication, UK, 1990.

[74] M.A. Green, "Solar cells operating principles, technology, and system applications", Prentice-Hall, New Jersey, 1982.

[75] A. Derrick, C. Francis, V. Bokalders, "Solar photovoltaic products", IT Publications, UK, 1989.

[76] U. Able-Thomas, R. Hill, P. O'Keefe and N.M. Pearsall, "Cost Effectiveness & Benefits of PV in The Gambia", Proc. World Renewable Energy Congress - III, Reading, U.K., September 1994, vol.1, pp248-250.

[77] Southern African Development Co-ordination Conference (SADCC), "Assessment of Applications and Markets for Solar Photovoltaic Systems in the SADCC Region" - Project AAA. 4.7.,1992.

[78] S.O.A. Sallah, "Giant step towards solar energy application in the Gambia", in Sunworld, 14, no.1, 1990.

[79] BP Solar Product Catalogue and Price List, (1992).

[80] U. Able-Thomas, "Photovoltaics for The Gambia - Management Strategies for Energy Technology Transfer", Internal Report, University of Northumbria at Newcastle, April 1993.

[81] A. Derrick et al., "Solar Photovoltaics Products", I.T. Publications Ltd., London, 1991.

[82] UNDP Project, "Small Scale Solar Pumping Systems", GLO/80/003.

[83] Director General - World Health Organization, Progress Report on Expanded Program on Immunization, 30th World Health Assembly, WHO Doc. A30/13, April 19, 1977.

[84] C.A. De Quadro, "More Effective Immunization", Proc. R. Soc. London, ser. B, 209 (1980) 111-118.

[85] M. Zaffran, "PV in Developing Countries Solar Energy for Primary Health Care", Proc. 11th EC Photovoltaic solar energy conference, Montreux, October 1992.

[86] The World Bank, "Pakistan: Photovoltaic Applications study", UNDP/World Bank energy sector management assistance programme report, Washington DC, USA 1989.

[87] M. Zaffran, "Solar refrigeration for the storage of vaccines in the expanded programme on immunization in developing countries", Proc. 10th EC Photovoltaic Solar Energy Conference, Lisbon, April 1991.

[88] B. McNelis, "Photovoltaics for developing countries", in Applications of Photovoltaics, Adam Hilger, Bristol, 1989.

[89] A. Derrick, J.M. Durand and T.J. Hart, "Solar powered vaccine refrigerators: Results of concerted action on infrastructure support", Proc. 9th EC Photovoltaic Solar Energy Conference, Freiburg, September 1989.

[90] Richard L. Field, "Review of Photovoltaic-powered refrigerator for medicines in developing countries", Solar Cells, 6(1982) 309-316.

[91] J. P. KENNA, "Cost & Performance Data on Diesel Engine Generators and Pumps", SAND87-7109 (Albuquer: Sandia National Laboratories, April 1987). Work performed by IT Power, Ltd.

[92] R. Hill and N.M. Pearsall, "Advances in Solar Energy Technology", Ed. W.H. Bloss and F. Pfisterer, Pergamon Press Oxford 1987, pp3952-3956.

[93] R. Hill, N.M. Pearsall and P. O'Keefe, "Energy Options - The Role of Alternatives in the World Energy Scene", IEE London 1987, pp26-29.

[94] S.O.A. Sallah, "Giant step towards solar energy application in the Gambia", in Sunworld, 14, no.1, 1990.

[95] Kenneth W. Cobb, "Assessment and conceptual design of PV hybrid systems", Engineering and Economics Research, Inc., P.A., and National Rural Electric Cooperative Association, DOE/NASA/0299-1 (Cleveland, OH: National Aeronautics and Space Administration, October 1983).

[96] R.W. Stacey, "Remote Community PV Application Investigation", preliminary report (Perth, Western Australia: Solar Energy Research Institute, April 1984).

[97] G.J. Jones and R.N. Chapman, "Photovoltaic/Diesel Hybrid System : The Design Process", Proc. 19th IEEE Photovoltaic Specialists Conference, Louisana, May 1987.

[98] T.M. Calloway, "Design of an Intermediate-Sized Autonomous Photovoltaic/Diesel Power Plant", SAND86-2136 (Albuquerque: Sandia National Laboratories, April 1986).

[99] Z. Benyahia, "Economic viability of photovoltaic systems as an alternative to diesel power plants", Proc. 9th European Photovoltaic Solar Energy Conference, Freiburg, Germany, September, 1989.

[100] M. Aubree, "Optimization of a PV/diesel engine generator hybrid system for a telecommunications microwave relay in France", 8th European Photovoltaic Solar Energy Conference, Florence, Italy, May 1988.

[101] Walter A. Chudson, "The International Transfer of Commercial Technology to Developing Countries", UNITAR, New York, U.S.A., United Nations Publication, No.13, 1971.

[102] Ann Johnston and Albert Sasson, "New Technologies and Development", Paris, France, United Nations, UNESCO, 1986.

[103] Frances Stewart, "Technology: Major issues for policy in the 1980's", In H. Singer, N. Hatti and R. Tandon, "Technology Transfer by Multinationals", New Delhi, India, Ashish Publishing House, Part 1, 1988.

[104] Frances Stewart, "International Technology Transfer: Issues and Options", World Bank Staff Working Paper, No. 344, Washington, D.C., U.S.A., World Bank, 1979.

[105] F.R. Root, "The Role of International Business in the Diffusion of Technology Innovation", Economic and Business Bulletin, Vol.20, No.4, Summer 1968, In T.L. ILGEN and T.J. Pempel, "Trading Technology", New York, U.S.A., Praeger Publishers, 1987.

[106] B. Danjani, "Technology Transfer 11: The North/South Dimension", Arab British Commerce, Year 12, No.5, December 1989.

[107] "North/South Technology Transfer: The Adjustments Ahead", OECD, Paris, France, 1981.

[108] M.A. Al-Tayyeb, "Information Technology Transfer to Saudi Arabia", In M.A. Marghalani, "Factors Affecting Information Technology Transfer in Developing Countries", Libri, International Library Review, Copenhagen, Denmark, Munksgaard International Publishers Ltd., Vol.37, No.3, September 1987.

[109] M.R. Bhagavan, "The Technological Transformation of the Third World: Strategies and Prospects", London, England, Zed Books Ltd., 1990.

[110] A. Emmanual, "Appropriate or Underdeveloped Technology", New York, U.S.A., John Wiley and Sons Publications, 1982.

[111] J. Baranson and R. Roark, "Trends in North/South Transfer of High Technology", In N. Rosenberg and C. Frischtak, "International Technology Transfer: Concepts, Measures and Comparisons", New York, U.S.A., Praeger Publishers, 1985.

[112] N. Sharif, "Management of Technology Transfer and Development", Bangalore, India, United Nations, Regional Centre for Technology Transfer, 1983.

[113] D. Spencer, "Technology Gap in Perspective", New York, U.S.A., Sparton Books, 1970.

[114] M.E. Goreish, "A Framework for Understanding Technology Transfer in the Arab World with Special Reference to the International Code of Conduct on Technology Transfer", Workshop on Legal Policies for Technology Transfer held in Kuwait, (19th-23rd September, 1981), Doha, Qatar, Gulf organisation for Industrial Consulting, 1981.

[115] W.A.P. Manser and S. Webley, "Technology Transfer to Developing Countries", The Royal Institute of International Affairs, No.3, London, England, 1979.

[116] S.J. Patel, "Transfer of Technology and Developing Countries", In N. Sharif, "Management of Technology Transfer and Development", United Nations Regional Centre for Technology Transfer, Bangalore, India, 1983.

[117] T.L. Ilgen and T.J. Pempel, "Trading Technology", New York, U.S.A., Praeger Publishers, 1987.

[118] "Guidelines for the study of the Transfer of Technology to Developing Countries", A Study by the UNCTAD Secretariat, Geneva, Switzerland, 1972, United Nations Publications, New York, U.S.A., 1972.

[119] C. Michalet, "The International Transfer of Technology and the Multinational Enterprises", In N. Sharif, "Management of Technology Transfer and Development", Bangalore, India, United Nations, Regional Centre for Technology Transfer, 1983.

[120] E.K.Y. Chen, "The Newly Industrialising Countries as Exporters of Technology in Asia-Pacific", In H. Singer, N. Hatti and R. Tandon, "Technology Transfer by Multinationals", New Delhi, India, Ashish Publishing House, Part 2, 1988.

[121] J. Baranson, "Technology Transfer Through the International Firm", American Economic Review, May 1970, In W.A. Chudson, "The International Transfer of Commercial Technology to Developing Countries", UNITAR, New York, U.S.A., United Nations Publication, No.13, 1971.

[122] J.N. Behrman, "National Interests and the multinational Enterprise: Tensions Among the North Atlantic countries", Englewood Cliffs, New Jersey, U.S.A., Prentice-Hall, 1970, In T.L. Ilgen and T.J. Pempel, "Trading Technology", New York, U.S.A., Praeger Publishers, 1987.

[123] Hellinger and Hellinger, "The Unemployment Problems Created by Multinational Corporations Activities in Latin America", 1975, In E.K.Y. Chen, "The newly Industrialising Countries as Exporters of Technology in Asia-Pacific", In H. Singer, N. Hatti and R. Tandon, "Technology Transfer by Multinationals", New Delhi, India, Ashish Publishing House, Part 2, 1988.

[124] A. Omer, "Channels and Mechanisms for Transfer of Technology", In "Technology Policies for Development and Selected Issues for Action", Proceedings of a Seminar Organised by Islamic Development Bank and UNCTAD, held in Jeddah, Saudi Arabia, in November 10-17, 1986, New York, U.S.A., United Nations Publication, 1988.

[125] Sharma, "The Role of Multinational Corporations in Industrialisation in the Asian Newly Industrialising Countries (NIC)", 1984, In E.K.Y. Chen, "The Newly Industrialising Countries as Exporters of Technology in Asia-Pacific", In H. Singer, N. Hatti and R. Tandon, "Technology Transfer by Multinationals", New Delhi, Ashish Publishing House, Part 2, 1988.

[126] J. Baranson, "Technology and the Multinationals", Lexington, Massachusetts, U.S.A., Lexington Books, 1978.

[127] J. Hagedoorm, "Organisation Modes of Inter-Firm co-operation and Technology Transfer", Technovation, The International Journal of Technological Innovation and Entrepreneurship, Oxford, England, Elsevier Science Publishers Ltd., Vol.10, No.1, February 1990.

[128] T.S. Kim, "The Korean Technology Development Corporation", Cambridge, Massachusetts, U.S.A., Massachusetts Institute of Technology, Fall 1983, In J. Baranson and R. Roach, "Trends in North-South Transfer of High Technology", In N. Rosenberg and C. Frischtak, "International Technology Transfer: Concepts, Measures and Comparisons", New York, U.S.A., Praeger Publishers, 1985.

[129] E. Mansfield and A. Romeo, "Technology Transfer to Overseas Subsidiaries by U.S. Based Firms", Research Paper, Pittsburgh, Pennsylvania, U.S.A., University of Pennsylvania, 1979.

[130] C.A. Mitchalet, "Transfer of Technology by Trans-National Corporations: Traditional versus New Forms", Seminar on Technology Policies in the Arab States, held in Paris, France, in December 14-18, 1981, New York, U.S.A., United Nations Publication, 1981.

[131] D. Frame, "Political Risk in International Technology Transfer", Journal of Technology Transfer, Vol.10, No.2, 1986.

[132] C.T. Stewart Jr., "Technology Transfer versus Diffusion: A Conceptual Clarification", Journal of Technology Transfer, Vol.12, No.1, 1987.

[133] R. Matthews, "Industrial Strategy and Technological Dynamism in Machine Tool Manufacture: Comparative Perspectives on India and Japan", Series No.7, Technology and Culture, Lund, Sweden, University of Lund, 1983, In J. Baranson and R. Roark, "Trends in North-South Transfer of High Technology", In N. Rosenberg and C. Frischtak, "International Technology Transfer: Concepts, Measures and Comparisons", New York, U.S.A., Praeger Publishers, 1985.

[134] B. Padgett, "Technology Mobility and Cultural Constraints", In M. Chatterji, "Technology Transfer in Developing Countries", London, England, Macmillan Press Ltd., 1990.

[135] D. Chudnosky, "Foreign Trademarks in Developing Countries", In H. Singer, N. Hatti and R. Tandon, "Technology Transfer by Multinationals", New Delhi, India, Ashish Publishing House, Part.2, 1988.

[136] U. Colombo, "Technology Transfer: The General Model", Paper Presented at the 3rd IRF Middle East Regional Meeting, held in Riyadh, Saudia Arabia, February 13-18, 1988, Riyadh, Saudia Arabia, Ministry of Communications, 1988.

[137] T. Ozawa, "Entrepreneurship and Technology on Economic Development", Asian Development Review, Vol.3, No.2, 1985.

[138] H.W. Singer, "Transfer of Technology: A One-Way Street", In H. Singer, N. Hatti and R. Tandon, "Technology Transfer by Multinationals", New Delhi, India, Ashish Publishing House, Part.1, 1988.

[139] J.D. Halvacek and V.A. Thompson, "The Joint Venture Approach to Technology Utilisation", In N. Sharif, "Management of Technology Transfer and Development", Bangalore, India, United Nation, Regional Centre for Technology Transfer, 1983.

[140] M. Cetron, "Technology Transfer: Where we Stand Today", In H.F. Davidson, M.J. Cetron and J.D. Goldhar, "Technology Transfer", Leiden, Denmark, Noordhoff International Publishing, 1974.

[141] G. Aseniero, "Technology and Development: NIEO's Quest for Technology Transfer", In H. Addo, "Transforming the World-Economy?", Tokyo, Japan, The United Nations University, 1984.

[142] F. Stewart, "Technology and Underdevelopment", London, England, Macmillan Press Ltd., 1978.

[143] N. Chantramonklasri, "The Development of Technological and Managerial Capabilities in the Developing Countries", In M. Chatterji, "Technology Transfer in Developing Countries", London, England, Macmillan Press Ltd., 1990.

[144] M. Cimoli and G. Dosi, "The Characteristics of Technology and the Development Process: Some Introductory Notes", In M. Chatterji, "Technology Transfer in the Developing Countries", London, England, Macmillan Press Ltd., 1990.

[145] H.K. Eldin, "Problems of Technology Transfer to Developing Countries", In T.M. Khalil, B.A. Bayraktar and J.A. Edosomwan, "Technology Management 1", Proceedings of the First International Conference on Technology Management, held in Miami, Florida, U.S.A., in February 17-19, 1988, Geneva, Switzerland, Inderscience Enterprises Ltd., 1988.

[146] M. Allahwerdi, "Methodology for Analysis of Obstacles and Their Remedies in Technology Transfer in the Arab Region", Seminar on Technology Policies in the Arab States, held in Beirut, Lebanon, in May 25-29, 1981, New York, U.S.A., United Nations Publication, July 22, 1981.

[147] B. Aasen, E. Hasen, A. Lotherington, A. Stenseth and H. Wilhite, "Analytical Perspectives on Technology Transfer", In M. Chatterji, "Technology Transfer in Developing Countries", London, England, Macmillan Press Ltd., 1990.

[148] T. Ozawa, "Macroeconomic Factors Affecting Japan's Technology Inflows and Outflows: The Postwar Experience", In N. Rosenberg and C. Frischtak, "International Technology Transfer: Concepts, Measures and Comparisons", New York, U.S.A., Praeger Publishers, 1985.

[149] J.R. Bright, "Research, Development and Technological Innovation", New York, U.S.A., Irwin Inc., 1964.

[150] Dahlman and Westphal, "Technological Effort in Industrial Development", In F. Stewart and J. James, "The Economics of New Technology in Developing Countries", London, England, Frances Printer, 1982.

[151] E.F. Schumacher, "Small is Beautiful", London, England, Blond and Briggs Ltd., 1973.

[152] L.A. Brown, "Innovation Diffusion: A New Perspective", London, England, Methuen and Company, 1981, In K. Acheampong, "On the Relevance of Client Participation in the Design and Implementation of Technology Transfer Programmes: The Case of the YMCA Rural Enterprises Guidance Association (REGA) Project", Paper Presented at the 12th Annual Meeting and International Symposium of the Technology Transfer Society, held in Washington, D.C., U.S.A., in June 23-25, 1987, Washington, D.C., U.S.A., Technology Transfer Society, 1987.

[153] Mathur, "Speech to the Sixth Asian Regional Conference of the I.L.O.", held in Tokyo, Japan, September 2-13, 1968", In F. Stewart, "Technology and Underdevelopment", London, England, Macmillan Press Ltd., 1978.

[154] A. Wad and M. Radnor, "Technology Assessment: Review and Implications for Developing Countries", Paris, United Nations, UNESCO Publications, 1984.

[155] C. Salomon-Bayet, "Modern Science and the Coexistence of Rationalities", Diogenes, Paris, France, No.126, 1984, In A. Johnston and A. Sasson, "New Technologies and Development", Paris, France, UNESCO, United Nations Publication, 1986.

[156] W A. Chudson, "The Multinational Corporation in Africa", Paper Submitted to a meeting of African Ministries of Industry, Addis Ababa, February 1971, In W.A. Chudson, "The International Transfer of Commercial Technology to Developing Countries", UNITAR, New York, U.S.A., United Nations Publication, No.13, 1971.

[157] S.L. Marshall, "Microelectronic Technology", Boston Technical Publishers, 1967.

[158] P. Siffert, "Possibilities of Ion implantation in silicon solar cell manufacturing", Proc. 4th EC PV Solar Energy Conference, pp901, Stresa, Italy, 10-14 May 1982.

[159] P.G. Werner, "Advance Slicing Techniques", Proc. 4th EC PV Solar Energy Conference, pp883, Stresa, Italy, 10-14 May 1982.

[160] A. Salam, "Science in the Third World", The First Edinburgh Medal Address, Edinburgh University Press, (1989).

[161] B. McNelis and J.M. Durand, "Photovoltaic Refrigerators and Lighting System for Zaire", Proc. 6th Photovoltaic Solar Energy Conference, London, April 1985.

[162] A. Derrick et al, "Solar Photovoltaics Products" IT Publications, UK, 1989.

[163] I. Chambouleyron and F.C. Marques, "Barriers to the Dissemination of PV in Third World Countries: The Brazilian Experience", Proc. 12th European Photovoltaic Solar Energy Conference, Amsterdam, April 1994.

[164] J.M. Huacuz V. and A.M. Martinez L., ATAS Bulletin 8, 1992, UN Publications 1992, UN, New York.

[165] 1992 Hiltec Solar Ltd. Product Catalogue, Newcastle Upon Tyne, UK.

[166] 1992/93 Engco Advanced Technology Product Catalogue, Stuttgart, Germany.

[167] 1993 Helios Technology Product Catalogue, Padova, Italy.

[168] R. Hill, "PV in Developing Countries", Proc. 9th EC PV Solar Energy Conference, Freiburg, 1989, pp.949.

[169] R. Hill, B. McNelis, E. Lorenzo, A. Sorokin and L. Guimaraes, "The Successful Implementation of PV in Developing Countries", Proc. 12th European Photovoltaic Solar Energy Conference, Amsterdam, April 1994.

[170] Project Sengalo-Allemand, Rapport d'Activites, SENEEC Dakar, November 1992 & April 1993.

[171] J. Aguilera and E. Lorenzo, Proc. 10th EC PV Solar Energy Conference, Lisbon, 1991, pp.1342.

[172] J.M. Huacuz V. and Ana Ma. Martinez L., "PV for rural electrification: Early Mexican experience", in "Prospects for Photovoltaics - Mass Production, Commercialisation and Application for Development", Eds. R. Hill, E. Omeljanovsky and I. Chambouleyron, ATAS Bulletin No.8, United Nations New York, 1992, p.177-194.

[173] D. Lovejoy, "Electrification of Rural Areas by PV", in "Prospects for Photovoltaics - Mass Production, Commercialisation and Application for Development", Eds. R. Hill, E. Omeljanovsky and I. Chambouleyron, ATAS Bulletin No.8, United Nations New York, 1992, p.139-152.

[174] Sir William Halcrow and Partners/IT Power Ltd., "Small Scale Solar Powered Irrigation Pumping Systems; The Technology, its Economics and Advancement", Report to World Bank, June 1983.

[175] Intermediate Technology Power Ltd., "An evaluation of photovoltaic applications for developing countries", Report Prepared for UNESCO, April 1986.

[176] "Evaluation of International Photovoltaic Projects", NIS Report SAND 85 7018/2, Report Prepared for US Department of Energy and USAID.

APPENDIX 1.

COSTINGS OF DIESEL GENERATORS & PV SYSTEMS FOR BANJUL INTERNATIONAL AIRPORT.

Operation of 58.8KVA Diesel Generator & Costs.

The costings presented below are the actual figures involved in operating the diesel generating system at BIA.

D1 = Cost of the present operating CS6 type Lister-Petter 58.8KVA generators = 2 x D186,000.00 ≡ $41,334.
PW (life=6yrs.) = $177,112.
LCC = $218,446

D2 = Cost of transportation & installation of both diesel generator = $820.
PW (life=6yrs.) = $3,514.
LCC = $4,334

D3 = Cost of electrical cables = $950.
PW (life=10yrs.) = $2,035.
LCC = $2,985

D4 = Annual replacement of oil & fuel filters = 2 x $360.
PW = $19,109.

D5 = Annual replacement of (2 x 300) litres of engine oil = $934.
PW = $24,788.

D6 = Annual maintenance of exciter groove = 2 x $667.
PW = $35,404.

D7 = Annual flushing of radiator = 2 x $178.
PW = $9,448.

D8 = Annual fuel consumption of (2 x 39,000) litres = $43,334.
PW = $1,150,084.

D9 = Annual maintenance runs of vehicles to site = $13,780.
PW = $365,721.

D10 = Annual manpower cost = $13,643
PW = $362,085

D11 = Total Life Cycle Cost (LCC) = $2,192,404.

D12 = Annualised LCC (LCC/25yrs) = $87,696.

All costings obtained in local currency then converted to US Dollars.

58.8KVA DIESEL GENERATOR'S OPERATING SAVINGS

<u>Diesel Generator Operational = 20h/day, hence life increases by 16.7%.</u>

S1 = Annual savings on replacement of oil & fuel filter = $120,
Total savings = 4 x $120 = $480 (for 4 years)

S2 = Annual savings on engine oil = $156
Total savings = 4 x $156 = $624

S3 = Annual savings on maintenance of exciter groove = $223
Total savings = 4 x $223 = $892

S4 = Annual savings on flushing of radiator = $59
Total savings = 4 x $59 = $236

S5 = Annual savings on fuel consumption = $7,237
Total savings = 4 x $7,237 = $28,948

S6 = Annual savings, vehicle maintenance runs to site = $1,200
Total savings = 4 x $1,200 = $4,800

S7 = Annual savings on manpower cost = $0

<u>Diesel Generator Operational = 16h/day, hence life increases by about 33.3%.</u>

S1 - Total savings = 4 x ($120 + $120) = $960

S2 - Total savings = 4 x ($156 + $156) = $1,248

S3 - Total savings = 4 x ($223 + $223) = $1,784

S4 - Total savings = 4 x ($59 + $59) = $472

S5 - Total savings = 4 x ($7,237 + $7,237) = $57,896

S6 - Total savings = 4 x ($1,200 + $1,200) = $9,600

S7 - Total savings = $0

OH = Operating Hours

Diesel Generator Operational = 12h/day, hence life increases by about 33.3%.

S1 - Total savings = $960 + $480 = $1,440

S2 - Total savings = $1,248 + $624 = $1,872

S3 - Total savings = $1,784 + $892 = $2,676

S4 - Total savings = $472 + $236 = $708

S5 - Total savings = $57,896 + $28,948 = $86,844

S6 - Total savings = $9,600 + $4,800 = $14,400

S7 - Total savings = $0

Diesel Generator Operational = 8h/day, hence life increases by about 33.3%.

S1 - Total savings = $1,440 + $480 = $1,920

S2 - Total savings = $1,870 + $624 = $2,494

S3 - Total savings = $2,676 + $892 = $3,568

S4 - Total savings = $708 + $236 = $944

S5 - Total savings = $86,844 + $28,948 = $115,792

S6 - Total savings = $14,400 + $4,800 = $19,200

S7 - Total savings = $0

Diesel Generator Operational = 4h/day, hence life increases by about 33.3%.

S1 - Total savings = $1,920 + $480 = $2,400

S2 - Total savings = $2,494 + $624 = $3,118

S3 - Total savings = $3,568 + $892 = $4,460

S4 - Total savings = $944 + $236 = $1,180

S5 - Total savings = $115,792 + $28,948 = $144,740

S6 - Total savings = $19,200 + $4,800 = $24,000

S7 - Total savings = $0

58.8KVA DIESEL GENERATOR'S OPERATING HOURS VERSUS SAVINGS

US ($)	S1	S2	S3	S4	S5	S6	S7	TOTAL SAVINGS
OH=4	2,400	3,118	4,460	1,180	144,740	24,000	0	179,898
OH=8	1,920	2,496	3,568	944	115,792	19,200	0	143,920
OH=12	1,440	1,872	2,676	708	86,844	14,400	0	107,940
OH=16	960	1,248	1,784	472	57,896	9,600	0	71,960
OH=20	480	624	892	236	28,948	4,800	0	35,980

CURRENT FUEL COSTS AT VARIOUS LOCATIONS IN THE GAMBIA - MAY 1994 (IN US$ PER LITRE).

	BANJUL	BRIKAMA	SOMA	FARAFENNI	KAUR	BASSE
PMS	0.778	0.781	0.787	0.787	0.788	0.789
AGO	0.556	0.559	0.564	0.564	0.566	0.567
KERO	0.544	0.548	0.564	0.564	0.566	0.573

PMS = Premium Motor Spirit (Petrol).
AGO = Automotive Gasoil (Gasoil).
KERO = Kerosene.

PV'S INSTALLATION & OPERATIONAL COST

P1 = PV array sized to supply daily power of 5.388KWx24h = 129.312KWh.

P2 = PV array peak power needed with adequate battery storage size for 3 days cloud period during lowest month daily irradiation of 4.5 sunhours = 3 x 129.312KWh/4.5 sunhours = 86.21KW_p.

P3 = Utilizing deep discharge batteries of 95% & accounting for power loss within the whole electrical network. The total peak power needed from PV array = 86.21KW_p x 1.1 = 94.82KW_p.

P4 = Cost of array system = 94.82KW_p x \$8,000$(KW_p)^{-1}$ = \$758,560.

P5 = Battery capacity = 129.312KWh x 3 x 1.05 = 407.34KWh

P6 = Cost of battery system = 407.34KWh x \$150$(KWh)^{-1}$ = \$61,100.
PW (life=5yrs.) = \$258,801.
LCC = \$319,901

P7 = Cost of electronic charge controller system and electrical accessories = 407.34KWh x \$4.00$(KWh)^{-1}$ = \$1,629.
PW (life=10yrs.) = \$3,489.
LCC = \$5,118

P8 = Annual maintenance & manpower cost = 365 x \$1.34 = \$489.
PW = \$12,981.

P9 = Cost of transportation & installation of PV system = \$1,500.

P10 = Cost of annual site visit/inspection = \$360.
PW = \$9,554.

P11 = Total Life Cycle Cost (LCC) = \$1,107,614.

P12 = Annualised LCC (LCC/25yrs) = \$44,305.

PV'S INSTALLATION & OPERATING COST

Costings for PV operating 4 hours per day

P1 = PV array sized to supply daily power of 5.388KW x 4h = 21.56KWh

P2 = PV array peak power needed for an average daily radiation of 5.5 Sunhours in the Gambia = 21.56KWh/5.5h x 2 = $7.84KW_p$

P3 = Compensating for power losses in batteries, cables & electrical network = 7.84 x $1.1KW_p$ = $8.63KW_p$

P4 = Cost of array system = $8.63KW_p$ x $\$8,000/KW_p$ = \$69,040

P5 = Battery capacity system = 21.56KWh x 1.05 = 22.64KWh

P6 = Cost of battery system = 22.64KWh x \$150/KWh = \$3,396
PW = \$3,396 X 4.24 = \$14,399
LCC = \$17,795

P7 = Cost of electronic charge controller system & electrical accessories = 22.64KWh x \$4/KWh = \$91
PW = \$91 X 2.14 = \$195
LCC = \$286

P8 = Annual maintenance & manpower cost = \$365 x \$1.34 = \$489
PW = \$12,981

P9 = Cost of transportation/installation of PV system = \$1,500

P10 = Cost of annual site visit/inspection = \$360
PW = \$9,554

P11 = Total life cycle cost (LCC) = \$109,656

P12 = Annualised LCC (LCC/25yrs) = \$4,386

Costings for PV operating 8 hours per day

P1 = 5.388 x 8 = 43.11KWh

P2 = 43.11/5.5 x 2 = 15.68KW_p

P3 = 15.68 x 1.1 = 17.25KW_p

P4 = 17.25 x $8,000/$KW_p$ = $138,000

P5 = 43.11 X 1.05 = 45.27KWh

P6 = 45.27 x $150 = $6,791
PW = $6,791 X 4.24 = $28,794 LCC = $35,585

P7 = 45.27KWh x $4/KWh = $181
PW = $181 X 2.14 = $387 LCC = $568

P8 = PW = $12,981

P9 = $1,500

P10 = PW = $9,554

P11 = TLCC = $198,188

P12 = ALCC = $7,928

Costings for PV operating 12 hours per day

P1 = 5.388 x 12 = 64.66KWh

P2 = 64.66/5.5 x 2 = 23.52KW_p

P3 = 23.52 x 1.1 = 25.87KW_p

P4 = 25.87 x $8,000/$KW_p$ = $206,960

P5 = 64.66 X 1.05 = 67.89KWh

P6 = 67.89 x $150 = $10,184
PW = $10,184 X 4.24 = $43,180 LCC = $53,364

P7 = 67.89KWh x $4/KWh = $272
PW = $272 X 2.14 = $582 LCC = $854

P8 = PW = $12,981

P9 = $1,500

P10 = PW = $9,554

P11 = TLCC = $285,213

P12 = ALCC = $11,409

Costings for PV operating 16 hours per day

P1 = 5.388 x 16 = 86.21KWh

P2 = 86.21/5.5 x 2 = 31.35KW_p

P3 = 31.35 x 1.1 = 34.49KW_p

P4 = 34.49 x \$8,000/KW_p = \$275,920

P5 = 86.21 X 1.05 = 90.5KWh

P6 = 90.5 x \$150 = \$13,575
PW = \$13,575 X 4.24 = \$57,558 LCC = \$71,133

P7 = 90.5KWh x \$4/KWh = \$362
PW = \$362 X 2.14 = \$775 LCC = \$1,137

P8 = PW = \$12,981

P9 = \$1,500

P10 = PW = \$9,554

P11 = TLCC = \$372,225

P12 = ALCC = \$14,889

Costings for PV operating 20 hours per day

P1 = 5.388 x 20 = 107.76KWh

P2 = 107.76/5.5 x 2 = 39.18KW_p

P3 = 39.18 x 1.1 = 43.10KW_p

P4 = 43.10 x \$8,000/KW_p = \$344,800

P5 = 107.76 X 1.05 = 113.2KWh

P6 = 113.2 x \$150 = \$16,980
PW = \$16,980 X 4.24 = \$71,995 LCC = \$88,975

P7 = 113.2KWh x \$4/KWh = \$453
PW = \$453 X 2.14 = \$969 LCC = \$1,422

P8 = PW = \$12,981

P9 = \$1,500

P10 = PW = \$9,554

P11 = TLCC = \$459,232

P12 = ALCC = \$18,369

PV'S INSTALLATION & OPERATIONAL COST FOR VARIOUS ARRAY PEAK POWER.

IN US DOLLARS ($)	P4	P6	P7	P8	P9	P10	P11	P12
OH = 4hr	69,040	17,795	286	12,981	1,500	9,554	109,656	4,386
OH = 8hr	138,000	35,585	568	12,981	1,500	9,554	198,198	7,928
OH = 12hr	206,960	53,364	854	12,981	1,500	9,554	285,213	11,409
OH = 16hr	275,920	71,133	1,137	12,981	1,500	9,554	372,225	14,889
OH = 20hr	344,800	88,975	1,422	12,981	1,500	9,554	459,232	18,369
OH = 24hr	758,560	319,901	5,118	12,981	1,500	9,554	1,107,614	44,305

58.8KVA DIESEL GENERATOR'S OPERATING HOURS VERSUS SAVINGS

US ($)	S1	S2	S3	S4	S5	S6	S7	TOTAL SAVINGS
OH=4	2,400	3,118	4,460	1,180	144,740	24,000	0	179,898
OH=8	1,920	2,496	3,568	944	115,792	19,200	0	143,920
OH=12	1,440	1,872	2,676	708	86,844	14,400	0	107,940
OH=16	960	1,248	1,784	472	57,896	9,600	0	71,960
OH=20	480	624	892	236	28,948	4,800	0	35,980

ECONOMIC ASSESSMENT OF HYBRID SYSTEM WITHIN A 4 YEAR PERIOD USING PRESENT OPERATING DIESEL GENERATING SYSTEM.

Daily Operating Hours Diesel / PV	PV's Annualised System Cost for 4 years ($)	Diesel's Savings on O&M costs ($)	Diesel's Additional Salvage Cost after 4 Years ($)	Hybrid Savings
4 / 20	73,476	179,898	2,000	108,422
8 / 16	59,556	143,920	1,600	85,964
12 / 12	45,636	107,940	1,300	63,604
16 / 8	31,712	71,960	1,000	41,248
20 / 4	17,544	35,980	600	19,036

Operation of 9.6KVA Diesel Generator & Costs.

In about 4 years time the present diesel generators would be due for replacement. The optimum strategy when replacing the present diesel generator sets would be to install a PV system plus a smaller diesel generator to form an optimum PV/diesel hybrid system.

The smallest available generator to satisfy the load of 5.388KW is a 9.6KVA generator supplying a continuous output of 7.6KVA, and costing $4,048 C.I.F. Banjul.

The costings below are the anticipated amount for operating a Lister-Petter 9.6KVA diesel generator at BIA.

A1 = Lister-Petter 9.6KVA diesel generator (C.I.F.) = $4,048.
PW (life=6yrs.) = $4,048 x 4.28 = $17,325.
LCC = $21,373

A2 = Transportation & installation = $520.
PW (life=6yrs.) = $520 x 4.28 = $2,226.
LCC = $2,746

A3 = Electrical cables = $930.
PW (life=10yrs.) = $930 x 2.14 = $1,990.
LCC = $2,920

A4 = Annual replacement of oil & fuel filters = $336.
PW = $336 x 26.54 = $8,917.

A5 = Annual replacement of 100 litres of engine oil = $156.
PW = $156 x 26.54 = $4,140.

A6 = Annual maintenance of exciter groove = $375.
PW = $375 x 26.54 = $9,953.

A7 = Annual flushing of radiator = $125.
PW = $125 x 26.54 = $3,318.

A8 = Annual fuel consumption of 29,784 litres = $16,547.
PW = $16,547 x 26.54 = $439,157.

A9 = Annual maintenance runs of vehicles to site = $10,335.
PW = $10,335 x 26.54 = $274,291.

A10 = Annual manpower cost = $13,643.
PW = $13,643 x 26.54 = $362,085.

A11 = Total Life Cycle Cost (LCC) = $1,128,900.

A12 = Annualised LCC (LCC/25yrs) = $45,156.

All costings obtained in local currency then converted to US Dollars.

9.6KVA DIESEL GENERATOR'S OPERATING COST

The costings presented below are the anticipated amount in operating a Lister-Petter 9.6KVA diesel generator for 20h/day.

A1 = Lister-Petter 9.6KVA diesel generator (C.I.F.) = $4,048.
PW (life=7yrs.) = $4,048 x 4.28 = $17,325.
LCC = $21,373

A2 = Transportation & installation = $520.
PW (life=7yrs.) = $520 x 4.28 = $2,226.
LCC = $2,746

A3 = Electrical cables = $930.
PW (life=10yrs.) = $930 x 2.14 = $1,990.
LCC = $2,920

A4 = Annual replacement of oil & fuel filters = $280.
PW = $280 x 26.54 = $7,431.

A5 = Annual replacement of 83.3 litres of engine oil = $130.
PW = $130 x 26.54 = $3,450.

A6 = Annual maintenance of exciter groove = $313.
PW = $313 x 26.54 = $8,307.

A7 = Annual flushing of radiator = $104.
PW = $104 x 26.54 = $2,760.

A8 = Annual fuel consumption of 24,820 litres = $13,899.
PW = $13,899 x 26.54 = $368,879.

A9 = Annual maintenance runs of vehicles to site = $8,613.
PW = $8,613 x 26.54 = $228,589.

A10 = Annual manpower cost = $13,643.
PW = $13,643 x 26.54 = $362,085.

A11 = Total Life Cycle Cost (LCC) = $1,008,540.

A12 = Annualised LCC (LCC/25yrs) = $40,342.

All costings obtained in local currency then converted to US Dollars.

9.6KVA Diesel Generator Operating for 16 Hours per Day

A1 = Lister-Petter 9.6KVA diesel generator (C.I.F.) = \$4,048.
PW (life=8yrs.) = \$4,048 x 3.23 = \$13,075.
LCC = \$17,123

A2 = Transportation & installation = \$520.
PW (life=8yrs.) = \$520 x 3.23 = \$1,680.
LCC = \$2,200

A3 = Electrical cables = \$930.
PW (life=10yrs.) = \$930 x 2.14 = \$1,990.
LCC = \$2,920

A4 = Annual replacement of oil & fuel filters = \$233.
PW = \$233 x 26.54 = \$6,184.

A5 = Annual replacement of 69.4 litres of engine oil = \$108.
PW = \$108 x 26.54 = \$2,866.

A6 = Annual maintenance of exciter groove = \$261.
PW = \$261 x 26.54 = \$6,927.

A7 = Annual flushing of radiator = \$87.
PW = \$87 x 26.54 = \$2,309.

A8 = Annual fuel consumption of 20,683 litres = \$11,583.
PW = \$11,583 x 26.54 = \$307,413.

A9 = Annual maintenance runs of vehicles to site = \$7,178.
PW = \$7,178 x 26.54 = \$190,504.

A10 = Annual manpower cost = \$13,643.
PW = \$13,643 x 26.54 = \$362,085.

A11 = Total Life Cycle Cost (LCC) = \$900,531.

A12 = Annualised LCC (LCC/25yrs) = \$36,021.

9.6KVA Diesel Generator Operating for 12 Hours per Day

A1 = Lister-Petter 9.6KVA diesel generator (C.I.F.) = $4,048.
PW (life=9yrs.) = $4,048 x 2.13 = $8,622.
LCC = $12,670

A2 = Transportation & installation = $520.
PW (life=9yrs.) = $520 x 2.13 = $1,108.
LCC = $1,628

A3 = Electrical cables = $930.
PW (life=10yrs.) = $930 x 2.14 = $1,990.
LCC = $2,920

A4 = Annual replacement of oil & fuel filters = $194.
PW = $194 x 26.54 = $5,149.

A5 = Annual replacement of 57.8 litres of engine oil = $90.
PW = $90 x 26.54 = $2,389.

A6 = Annual maintenance of exciter groove = $218.
PW = $218 x 26.54 = $5,786.

A7 = Annual flushing of radiator = $73.
PW = $73 x 26.54 = $1,937.

A8 = Annual fuel consumption of 17,236 litres = $9,653.
PW = $9,653 x 26.54 = $256,191.

A9 = Annual maintenance runs of vehicles to site = $5,982.
PW = $5,982 x 26.54 = $158,762.

A10 = Annual manpower cost = $13,643.
PW = $13,643 x 26.54 = $362,085.

A11 = Total Life Cycle Cost (LCC) = $809,517.

A12 = Annualised LCC (LCC/25yrs) = $32,381.

9.6KVA Diesel Generator Operating for 8 Hours per Day

A1 = Lister-Petter 9.6KVA diesel generator (C.I.F.) = $4,048.
PW (life=10yrs.) = $4,048 x 2.14 = $8,663.
LCC = $12,711

A2 = Transportation & installation = $520.
PW (life=10yrs.) = $520 x 2.14 = $1,113.
LCC = $1,633

A3 = Electrical cables = $930.
PW (life=10yrs.) = $930 x 2.14 = $1,990.
LCC = $2,920

A4 = Annual replacement of oil & fuel filters = $162.
PW = $162 x 26.54 = $4,299.

A5 = Annual replacement of 48.2 litres of engine oil = $75.
PW = $75 x 26.54 = $1,991.

A6 = Annual maintenance of exciter groove = $182.
PW = $182 x 26.54 = $4,830.

A7 = Annual flushing of radiator = $61.
PW = $61 x 26.54 = $1,619.

A8 = Annual fuel consumption of 14,363 litres = $8,044.
PW = $8,044 x 26.54 = $213,488.

A9 = Annual maintenance runs of vehicles to site = $4,985.
PW = $4,985 x 26.54 = $132,302.

A10 = Annual manpower cost = $11,369.
PW = $11,369 x 26.54 = $301,733.

A11 = Total Life Cycle Cost (LCC) = $677,526.

A12 = Annualised LCC (LCC/25yrs) = $27,101.

9.6KVA Diesel Generator Operating for 4 Hours per Day

A1 = Lister-Petter 9.6KVA diesel generator (C.I.F.) = $4,048.
PW (life=11yrs.) = $4,048 x 2.16 = $8,744.
LCC = $12,792

A2 = Transportation & installation = $520.
PW (life=10yrs.) = $520 x 2.14 = $1,113.
LCC = $1,633

A3 = Electrical cables = $930.
PW (life=10yrs.) = $930 x 2.14 = $1,990.
LCC = $2,920

A4 = Annual replacement of oil & fuel filters = $135.
PW = $135 x 26.54 = $3,583.

A5 = Annual replacement of 40.2 litres of engine oil = $62.5.
PW = $62.5 x 26.54 = $1,659.

A6 = Annual maintenance of exciter groove = $152.
PW = $152 x 26.54 = $4,034.

A7 = Annual flushing of radiator = $51.
PW = $51 x 26.54 = $1,354.

A8 = Annual fuel consumption of 11,969 litres = $6,703.
PW = $6,703 x 26.54 = $177,898.

A9 = Annual maintenance runs of vehicles to site = $4,154.
PW = $4,154 x 26.54 = $110,247.

A10 = Annual manpower cost = $11,369.
PW = $11,369 x 26.54 = $301,733.

A11 = Total Life Cycle Cost (LCC) = $617,853.

A12 = Annualised LCC (LCC/25yrs) = $24,714.

PROPOSED HYBRID SYSTEM

TABLE 6.4 - 9.6KVA DIESEL GENERATOR'S INSTALLATION & OPERATIONAL COST FOR VARIOUS OPERATING HOURS.

US ($)	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
OH=4	12,792	1,633	2,920	3,583	1,659	4,034	1,354	177,898	110,247	301,733	617,853	24,714
OH=8	12,711	1,633	2,920	4,299	1,991	4,830	1,619	213,483	132,302	301,733	677,526	27,101
OH=12	12,670	1,633	2,920	5,149	2,389	5,786	1,937	256,191	158,762	362,085	809,517	32,381
OH=16	17,123	2,200	2,920	6,184	2,866	6,927	2,309	307,413	190,504	362,085	900,531	36,021
OH=20	21,373	2,746	2,920	7,431	3,450	8,307	2,760	368,879	228,589	362,085	1,008,540	40,342
OH=24	21,373	2,746	2,920	8,917	4,140	9,953	3,318	439,157	274,291	362,085	1,128,900	45,156

PV'S INSTALLATION & OPERATIONAL COST FOR VARIOUS ARRAY PEAK POWER.

IN US DOLLARS ($)	P4	P6	P7	P8	P9	P10	P11	P12
OH = 4hr	69,040	17,795	286	12,981	1,500	9,554	109,656	4,386
OH = 8hr	138,000	35,585	568	12,981	1,500	9,554	198,198	7,928
OH = 12hr	206,960	53,364	854	12,981	1,500	9,554	285,213	11,409
OH = 16hr	275,920	71,133	1,137	12,981	1,500	9,554	372,225	14,889
OH = 20hr	344,800	88,975	1,422	12,981	1,500	9,554	459,232	18,369
OH = 24hr	758,560	319,901	5,118	12,981	1,500	9,554	1,107,614	44,305

TOTAL COST OF PROPOSED HYBRID SYSTEM

DAILY OH PV + D.GEN	P11	P12	A11	A12	TOTAL COST ($)	ANNUALISED TOTAL COST ($)
0h + 24h	---	---	1,128,900	45,156	1,128,900	45,156
4h + 20h	109,656	4,386	1,008,540	40,342	1,118,196	44,728
8h + 16h	198,188	7,928	900,531	36,021	1,098,719	43,949
12h + 12h	285,213	11,409	809,517	32,381	1,094,730	43,790
16h + 8h	372,225	14,889	677,526	27,101	1,049,751	41,990
20h + 4h	459,232	18,369	617,853	24,714	1,077,085	43,083
24h + 0h	1,107,614	44,305	---	---	1,107,614	44,305

APPENDIX 2

A2 ENGINEERING DESCRIPTION OF THE POWER SUPPLY FOR NAVAIDS AT BIA

The proposed cost effective power supply for BIA is a PV/diesel hybrid system as discussed in chapter 6. The schematic diagram of the proposed system is illustrated in figure A2.1.

A2.1 DESCRIPTION OF THE NAVAIDS LOADS

The equipment to be powered is: a Doppler VHF Omni-Range (DVOR), a Distance Measuring Equipment (DME), an Outer Marker (OM), a UHF Communications Link (UCL) and an air-conditioner (ACON). These pieces of equipment are located in a pre-fabricated fibreglass building measuring 4m by 8m with a height of 3m and this is shown in figure A2.2. There is only a single opening into the building which is a door measuring 2m by 0.5m. The whole building has to be air-conditioned in order not to affect the performance of the equipment. It is very important that the output cables from the DVOR, DME and OM are kept reasonably cool in order not to affect the output signals being fed to the antennas. Duty technicians and engineers man the building on a 24 hour basis. Hence, they need a reasonably cool environment to work effectively.

The navaids building and some of the equipment are shown in figures A2.2 - A2.5.

(a) DVOR

This is used by aircraft for angle information (see figure A2.3). It gives the bearing of the centre line of the runway. The power requirement for this equipment is 22A at 24V DC.

The Racal Avionics Doppler VOR beacon type DVB Mk II is a medium range navigational aid fully conforming to the requirements of International Civil Aviation Organisation (ICAO) annex 10. The equipment is all solid state except for functional test switches and changeover relays.

The DVOR has duplicated transmitting and monitoring equipment to ensure continuity of service. The standby transmitter is operated into dummy loads continuously and change-over, in the event of failure in the main transmitter, is effected automatically with the minimum break of service.

The antenna system (see figure A2.4) comprises 49 omni-directional alford loops with horizontally polarised radiation. One centre antenna radiates the amplitude modulated carrier (reference signal plus speech and identity) and 48 antennas, equally spaced on a circle of 13.5m diameter sequentially radiate the double sideband sub-carrier (variable phase signal). The centre antenna is provided with a mounting support for the DME antenna. The antenna system is mounted on a counterpoise of 30.5m diameter. The height of the counterpoise is arranged so that it gives clearance above the surrounding local obstructions and to allow the equipment shelter to be located underneath. The counterpoise is electrically bonded and of mechanical strength sufficient to withstand environmental extremes.

Facility for remote control and supervision of the system from the equipment room at BIA (30km away) is available. The remote control signals are transmitted and received via the UCL.

(b) DME

This is used by aircraft for distance information. It tells the pilot the distance of the aircraft from the navaids site. The power requirement for this equipment is 10A at 120V DC.

This equipment uses a transponder for receiving and transmitting signals from and to an airborne-craft. The transponder is activated by interrogation from aircraft. A communications channel and an identity code are then established between the DME and the aircraft. The time period taken by the aircraft to respond to the DME interrogations is calculated by the DME. The DME then transmits the aircraft's distance from the navaids site and this information is displayed in the cockpit of the aircraft.

(c) OM

This is used by aircraft for position information. It is part of the instrument landing system, which aids the aircraft in proper approach and touch down procedures. The power requirement for this equipment is 1.5A at 24V DC.

This equipment (shown in figure A2.5) is used as a locator navigational aid conforming to the requirements of ICAO annex 10. The transmitter output is 1.5W and is amplitude modulated by a keyed tone. An automatic solid state call-sign generator is included, having a capacity of any five letters of the alphabet repeated up to ten times per minute.

Also included are dual alarm circuits which monitor the radio frequency (R/F) power output, call sign integrity and power supply state. The equipment has a dual transmitter installed with either unit on standby and automatic changeover facilities. Either transmitter can be selected as cold standby.

A remote control system is incorporated with which various functions of the equipment are monitored and displayed at a remote point. This remote point is the equipment room at BIA. The transmitter could be controlled by the same system.

Adequate built-in meter circuits are included, allowing monitoring of all critical circuits. The power output devices are incorporated on a modular power amplifier assembly. The equipment is powered from a 24V DC power source.

(d) UCL

This transmits voice and status information of each piece of equipment to the equipment room at the airport. The power requirement for this equipment is 1A at 24V DC.

This equipment transmits (Tx) and receives (Rx) radio signals in the UHF band and the nominal transmitter output is 10W. The various status of all the equipment at the navaids site is frequency multiplexed, modulated and then transmitted via the antenna by this equipment. The received UHF radio signal at the equipment room in BIA is demodulated and then displayed on the equipment status panel. Control buttons on this panel could also be activated. The modulated Tx signal is received by the UCL at Koloro for decoding and transmission to the respective equipment.

This equipment also has facilities for the transmission and reception of audio signals. This enables the technical staff and the air-traffic control officers to communicate between each other.

(e) ACON

It keeps the building and equipment cool for the proper operation of both electronic components and the technical staff. The power requirement for this equipment is 25.66A at 120V DC.

(f) LIGHTING

The light bulbs provide light for the building. The power requirement for this equipment is 1A at 24V DC.

A2.2 IMPROVEMENT IN ACON'S EFFICIENCY

The first step in designing a cost-effective PV power supply is to seek to reduce the demand of the equipment to be supplied. The navaids are built to international standards and can not be modified without affecting the certification of Banjul International Airport. The biggest load is the ACON, consuming about 63% of the total energy, and methods which could potentially reduce this demand were studied.

(a) Passive Cooling

The building cannot be cooled by passive means because of International Civil Aviation Organisation's (ICAO) regulation, forbidding objects to be placed within a 200m radius of the antennas. Even the grass around the building has to be kept very low at all times in order not to affect the radiated signals from the antennas.

(b) Peltier Coolers or Heat Pumps

The installation of such devices on the navaids equipment is prohibited by the manufacturer since it invalidates the warranty on the equipment. If the ACON is replaced by these devices the building would be too hot for any personnel to do effective work.

It is concluded that the total power demand could be reduced only if the entire building and equipment is replaced by more energy efficient systems having the approval of the ICAO.

A2.3 PV/DIESEL HYBRID SUB-SYSTEMS

The installation of the PV/diesel hybrid system comprises the following sub-systems interconnected to produce the complete power supply system (see figure A2.1):-

(a) PV array and supporting structures.

(b) DC regulator and battery storage system.

(c) Controlling unit and battery status monitor.

(d) Diesel generator and control panel.

(e) AC-DC converter and DC regulator.

(f) Navaids loads housed in a pre-fabricated fibreglass building with external antennas.

(a) PV Array Field

The optimum cost effective PV/diesel hybrid system has been obtained in chapter 6 as 16 and 8 hours of daily operation for PV and diesel generator systems respectively. The costings methodology of the PV/diesel hybrid system is given in appendix 1.

The PV array of the hybrid system has been designed for a total peak power of 34.5kWp output. This peak power value satisfies both the load for an average daily period of 16 hours and also compensates for power losses in batteries, cables and electrical network.

The PV array field consists of 464 solar modules, BP Solar Ltd type - BP275. Each module consists of 36 individual solar cells connected in series of 125mm monocrystalline silicon pseudo square cells. These cells are encapsulated to form a rectangular solar module.

The 36 cells are arranged in two strings each incorporating a by-pass diode. The positive and negative connections from the module are each terminated in a weatherproof plastic terminal box, which also incorporates the by-pass diodes.

Each module provides a peak power output of about 75W at a DC peak power point voltage and current of 17V and 4.45A respectively. The modules are arranged in sections each containing 4 modules. The output from the modules in each section are connected in series. Two adjacent sections each of 4 modules are connected in series to form a sub-array of 8 modules with a nominal terminal voltage of 130V DC. The positive and negative output leads from the sub-array are terminated in a junction box incorporating an isolator. The metallic array structures are electrically connected together and to ground as a safe guard against lighting strike.

The output from each of the 58 sub-arrays is transferred to the DC switching control cabin via a 2 core PVC insulated cable where the outputs are parallelled.

(b) DC Regulator and Battery storage System

The power produced by the PV array is continuously varying. The regulator essentially manages the rate at which the battery unit is charged. It prevents damage to the battery by over charging or discharging. The functioning of this unit is controlled by the control unit and battery status monitor.

The battery unit comprises 58 sets in parallel of 5 batteries each per set connected in series. Each battery has a nominal voltage of 24V.

(c) Controlling Unit and Battery Status Monitor

The controlling unit through the DC regulator will asses the status of the battery unit. As the battery unit voltage (~120V) approaches a fully charged level the charge from the array will be cut to a float or "top-up" charge level. This is just sufficient to maintain full charge, but will prevent gassing and subsequent loss of water. If the battery unit is near the fully discharged voltage the controlling unit will activate the diesel generator via the control panel. It will also cut the power supply from the battery unit to the loads and then activate the charging mode of the battery from the diesel generator. The diesel generator will stay on for a minimum of 4 hours or until the battery unit is almost fully charged. This is in order to avoid degrading the diesel generator efficiency and hence reduce the benefits of the hybrid system (as explained in chapter 6).

The 120V to 130V DC outputs from the battery unit and AC-DC converter unit are fed into this unit. There are two outputs from this unit connected to the navaid loads, i.e. 120V and 24V (see figure A2.1).

(d) Diesel Generator and Control Panel

This is a Lister Petter 9.6kVA AC generator with a power factor of 0.8. The nominal output voltage from the control panel is 240V alternating at a frequency of 50Hz. The output power is fed to an AC-DC converter and regulator.

(e) AC-DC Converter and Regulator

This section converts the generated AC power from the control panel into a regulated DC power. The regulated DC power is of a nominal voltage of 130V which is fed into the controlling unit for stepping down to 120V and 24V. The controlling unit then regulates the amount of power being fed into the loads (120V & 24V DC) and the charging of the battery unit (129V nominal).

(f) Navaids Loads

These loads have been discussed in section A2.1.

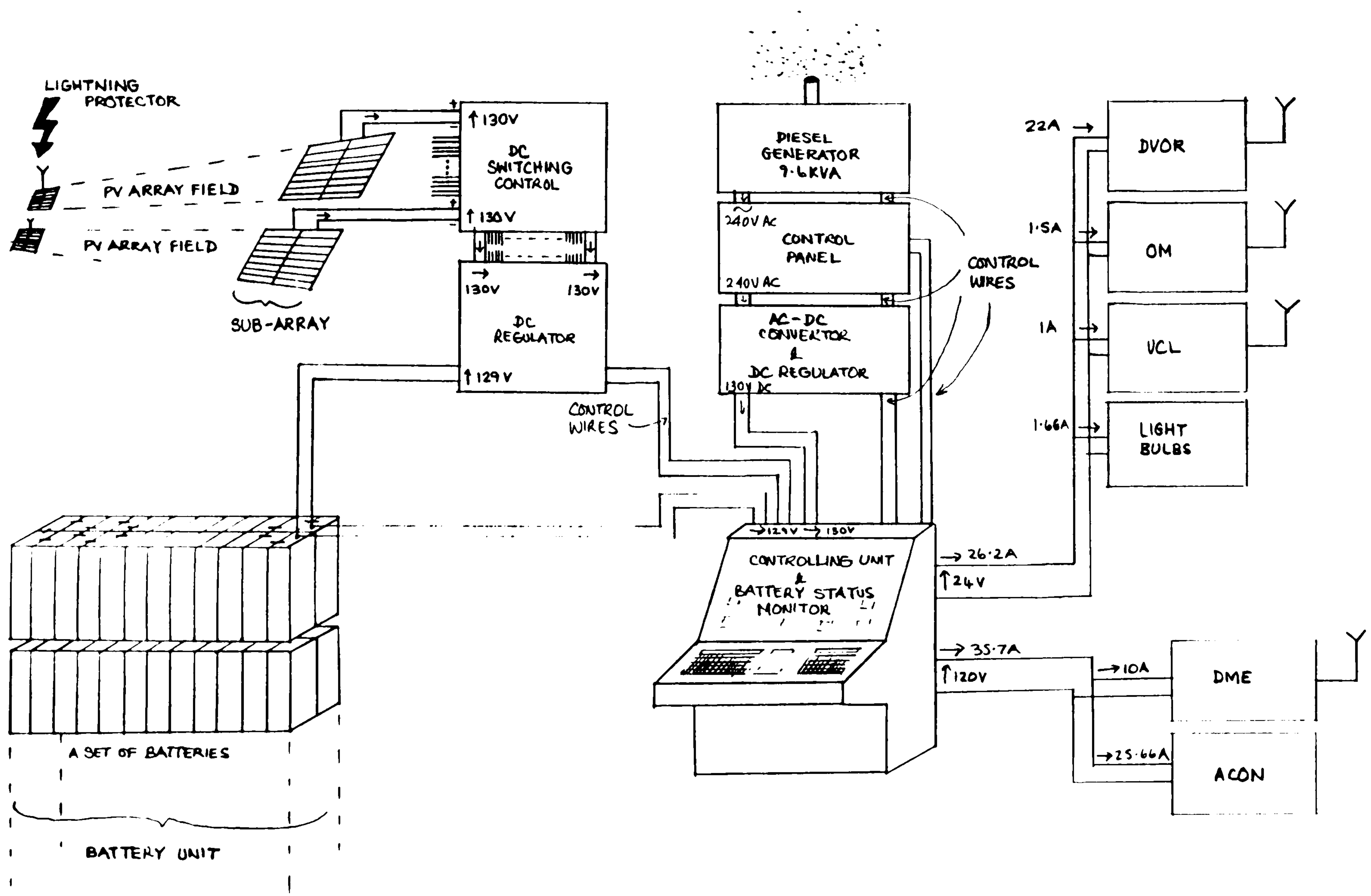


Figure A2.1 PV/Diesel Hybrid System for BIA

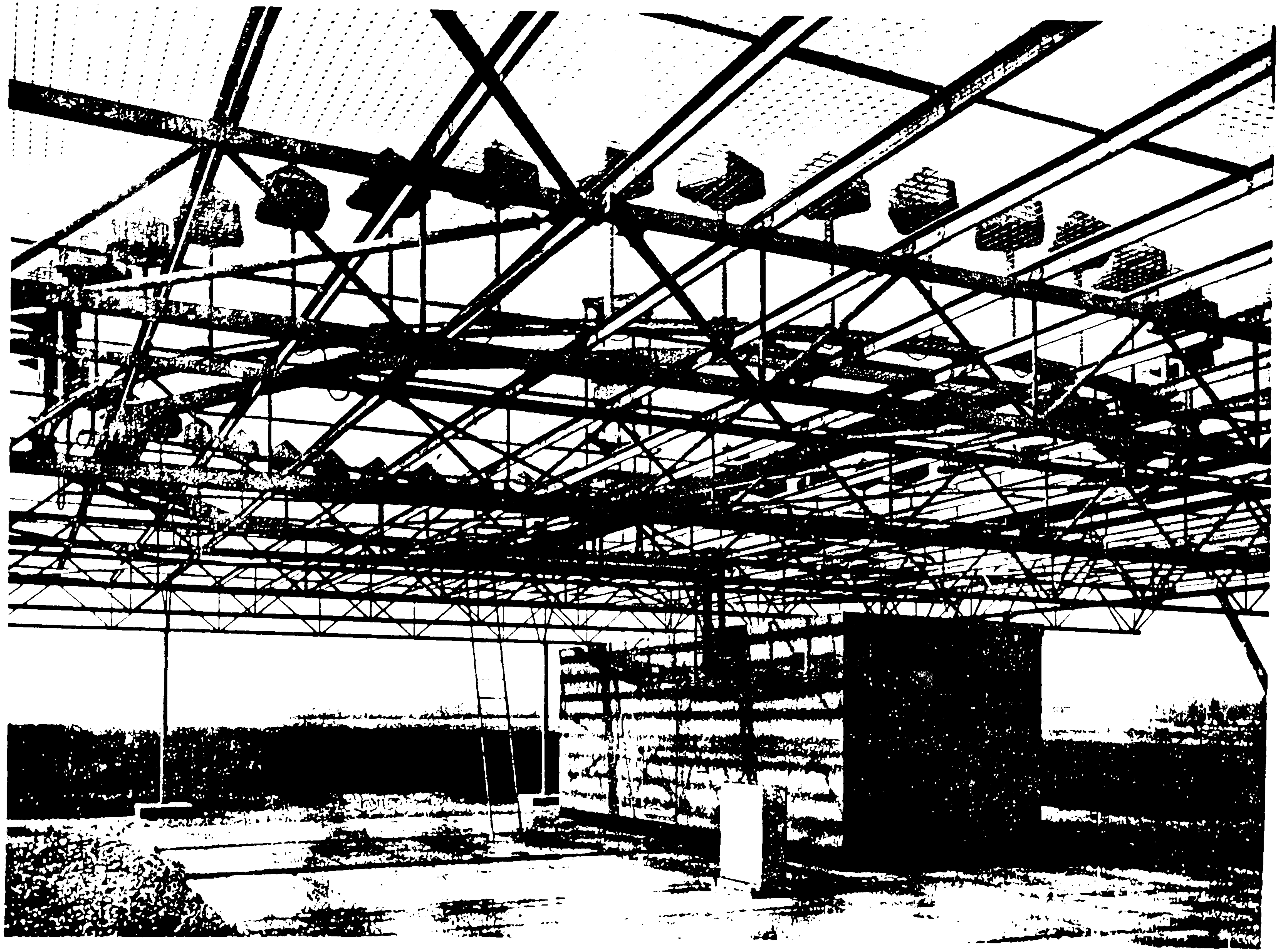


Figure A2.2 The Prefabricated Fibreglass Building, Housing the Navaids at BIA

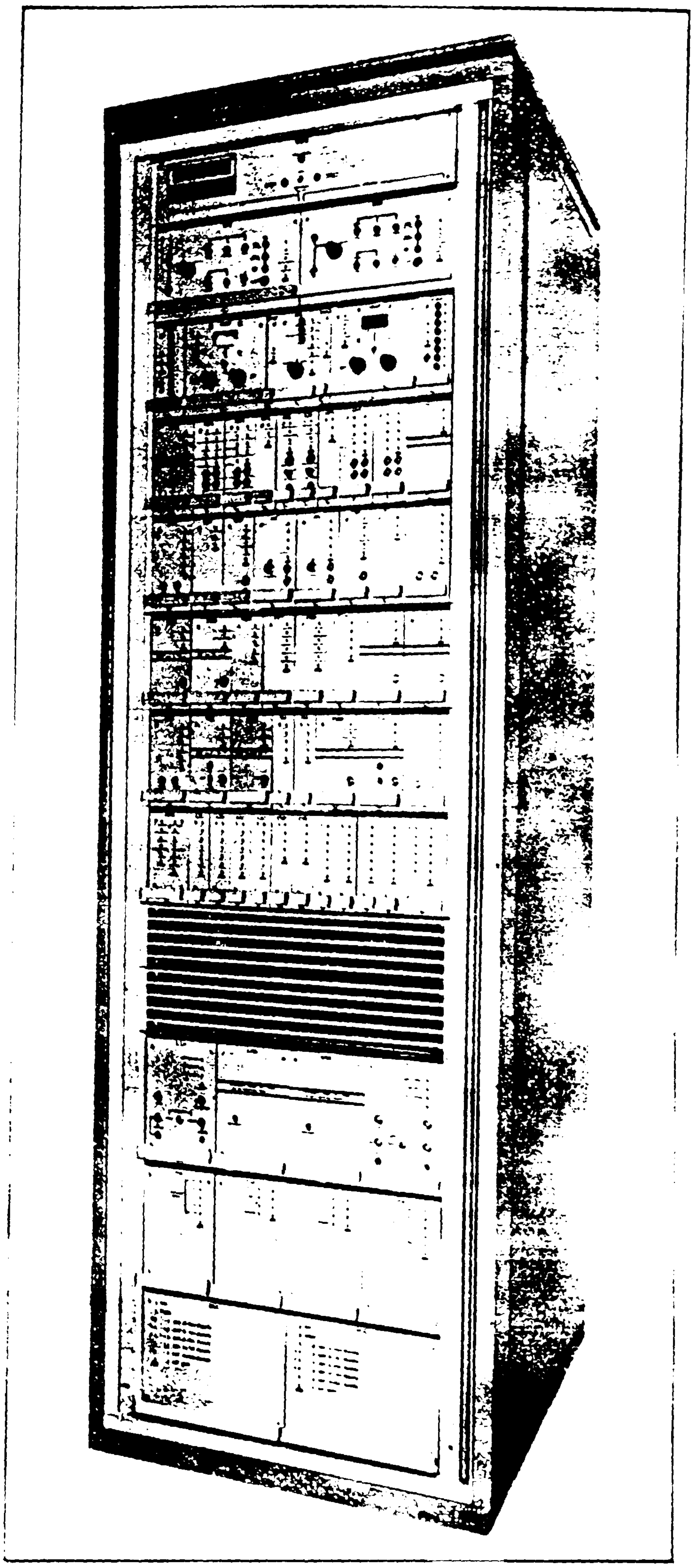


Figure A2.3 The DVOR Equipment at BIA

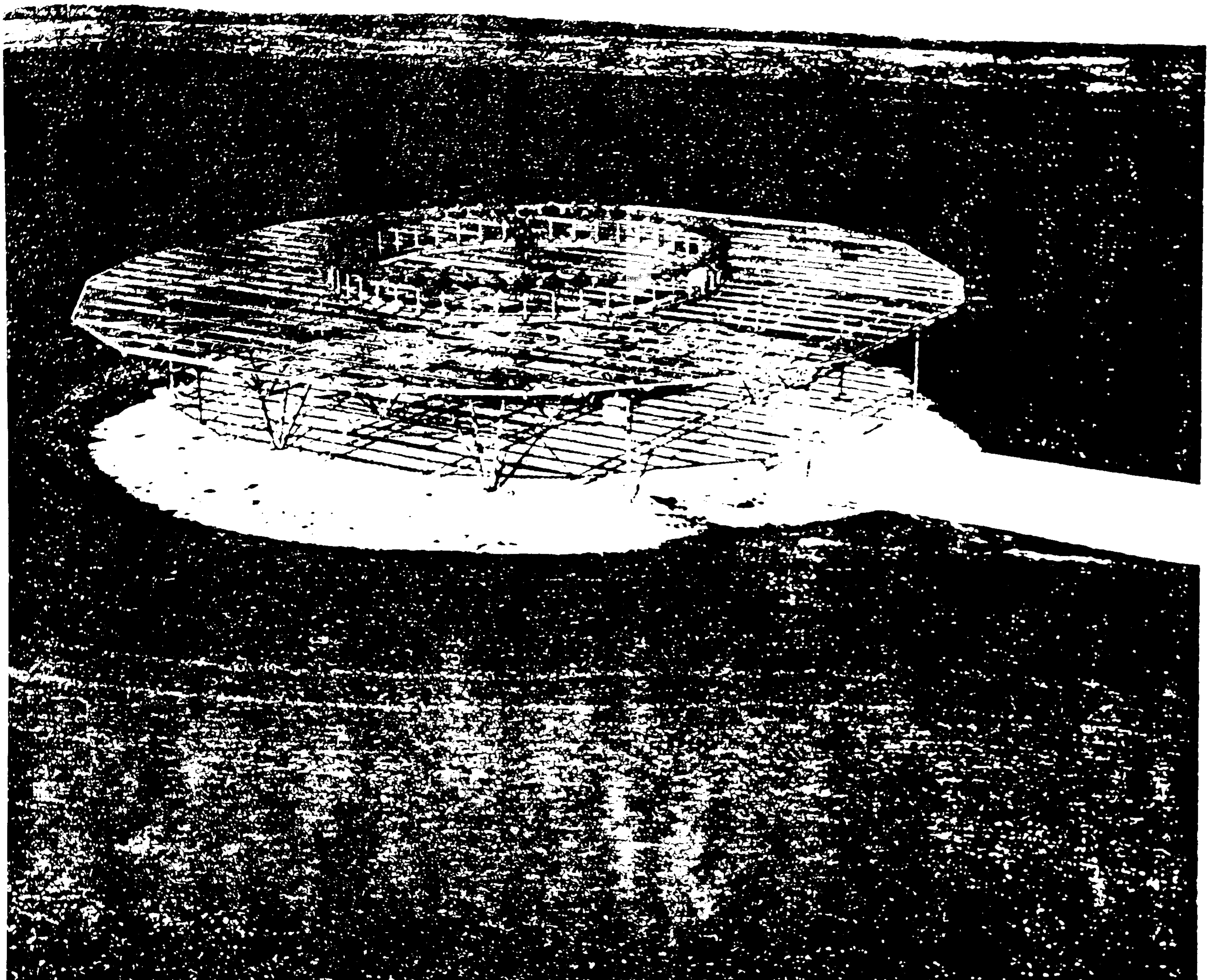


Figure A2.4 The DVOR Antenna System

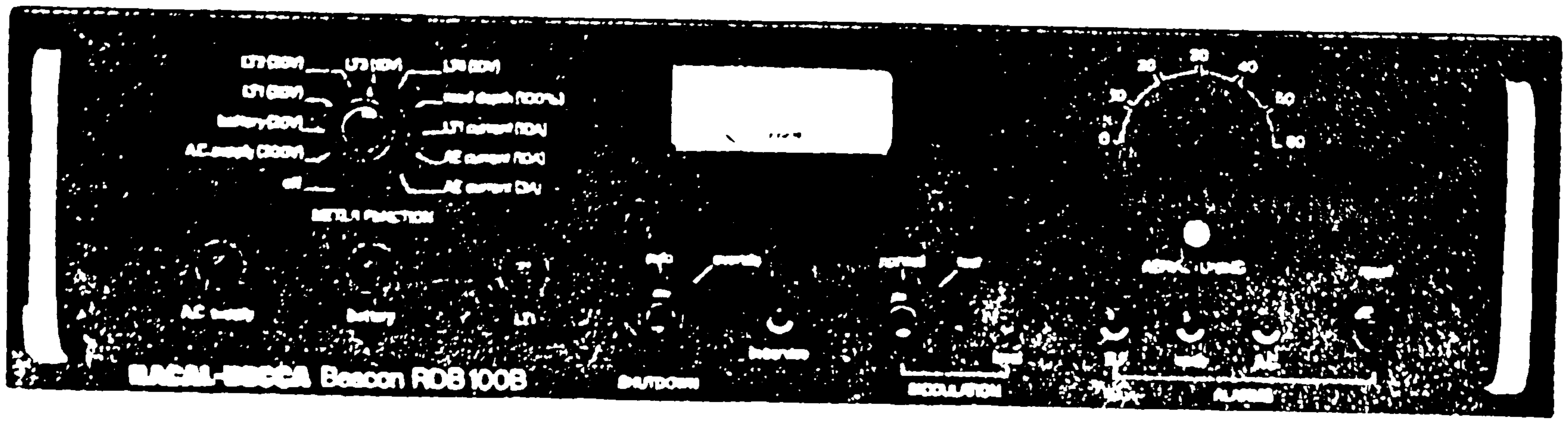


Figure A2.5 The Outer Marker

APPENDIX 3

SAMPLE TENDER DOCUMENT FORMAT FOR THE SUPPLY, INSTALLATION, TEST AND COMMISSION OF PV SYSTEM AT BIA.

1. INSTRUCTIONS TO TENDER

The Gambia Civil Aviation Authority (GCAA) invites tenders for the design, manufacture, supply, delivery, installation, test and commission of a complete PV system for Banjul International Airport (BIA). The PV system is to power the navigational aids and communications system at Kuloro in The Gambia. The specification of the tender is given below.

1.1 Tender Procedure

The schedule for the purchase of system is as follows:-

Tender forms issued by	..........(day)..........(month)..........(year)
Completed tenders to be returned by	..........(day)..........(month)..........(year)
Tenders awarded by	..........(day)..........(month)..........(year)
Systems to be delivered by	..........(day)..........(month)..........(year)

The original tender shall be in the English language and shall be filled out in ink or typewritten and will be made a part of the awarded contract.

1.2 Adjudication Process

Tenders will be primarily considered for:

(1) Performance

(2) Durability

(3) Cost effectiveness

(4) Experience of the tender

The GCAA will not be bound to award a contract to the lowest or any tender.

2. SPECIFICATION

2.1 Scope

This specification is for the design, manufacture, supply, delivery, installation, test and commission of a turnkey contract.

The system to be supplied shall include:-

(1) PV modules and array support structure.

(2) Load equipment to be specified.

(3) All control equipment and wiring.

(4) All fixings and ancillaries necessary for complete construction and commissioning.

(5) Tools needed for assembly and maintenance.

(6) Spare parts for proper operation of the system.

(7) Documentation.

(8) Training of GCAA personnels for proper maintenance of system to component level.

2.2 Design

The complete system shall be robust and capable of withstanding hard usage in a harsh environment. It shall be resistant to damage from accidental misuse and reasonably resistant to vandalism and the attentions of animals, wild or domestic.

The system shall be designed for assembly, operation and servicing by trainee technicians under the guidance of a trained technician or engineer. The requirement for special tool or instruments to install and maintain the system shall be minimised and all tools (including circuit diagrams and relevant literature) needed for installation shall be supplied with the system. Foundations or other preparatory work shall be as simple as practicable.

The system shall be designed for assembly from units which can be packed in containers small enough to be easily man-handled and transported on small vehicles.

The system shall be designed to operate for a lifetime of 25 years with minimum need for replacement of components and deterioration of performance. Routine maintenance shall be minimised and maintenance work necessary shall be as simple as possible, requiring only a few basic tools for its execution.

2.3 Environmental Conditions

The system shall be designed to meet the requirements of this specification under the following environmental conditions:-

(1) Ambient air temperature between $9^{o}C$ and $48^{o}C$.

(2) Relative humidity up to 100% at an ambient temperature of $48^{o}C$.

(3) wind speed up to 35m/s.

(4) a maximum altitude above sea level of 100m

The system should also be resistant to the following extremes of environment:-

(1) Sand storms.

(2) Heavy gust of wind and rain.

The contractor shall state the limits of environmental conditions under which the system is designed to operate.

2.4 Standards

PV modules shall comply with the test requirements of the current PV module control test specifications of the International Electro-technical Committee (IEC), based on existing United States, European and Japanese standards.

2.5 Performance Requirement

2.5.1 Location

The system to be supplied is to be located as detailed below:-

(1) Kuloro in the Western Division of The Gambia.

(2) Latitude = $13.4^{O}N$

(3) Longitude = $15^{O}W$

2.5.2 Required Performance

The system should provide average daily power that is adequate to power all the load and charge the batteries for an availability of greater than 95% each month. The load and its DC power ratings to be powered on a 24 hour basis are:-

(1) DVOR - 24V, 22A

(2) DME - 120V, 10A

(3) OM - 24V, 1.5A

(4) UCL - 24V, 1A

(5) ACON - 120V, 25.7A

A ten year (1982-92) mean daily solar radiation (kW/m^2) for various places in the Gambia will be supplied.

2.5.3 Installation Details

The sketch of the site and equipment room (see figures A2.2 & A2.4).

2.6 <u>Spare Parts</u>

The contractor shall supply with the system sufficient consumable items which may need replacement to last for 5 years of operation. The contractor shall also ensure that spares can be obtained/purchased for the remaining life-span of the PV system.

2.7 <u>Packing for Shipment</u>

All equipment shall be carefully and suitably packed for the specific means of transportation to be used, so that it is protected against all weather and other conditions to which it may become subject.

Complete assembly and operating instructions are to be included in packing.

2.8 Documentation

Prior to shipment of the equipment, the contractor shall submit to the purchaser the following documents of which copies shall also be shipped with the system:-

(1) A list of components and assemblies to be shipped including all spare parts and tools.

(2) The size, weight and packing list for each package in the shipment.

(3) Assembly instructions.

(4) Operating instructions.

(5) Instructions for all maintenance operations and the schedule for any routine maintenance requirements.

(6) Sufficient descriptions of spare parts and components to permit identifications for ordering replacement.

All documents shall be in the English language.

2.9 Tools

The contractor shall provide two sets of any special tools and other equipment that are required for erecting, operating, maintaining and repairing the equipment. Special tools shall include such items as Allen or socket keys, box spanners, feeler gauges, grease guns, etc. A single set of all other tools required for erection shall also be supplied.

2.10 Insurance

The contractor shall arrange for the equipment to be comprehensively insured for its full value from the time it leaves his premises until clearance from customs at the point of entry into the country of installation.

2.11 Warranty

The contractor shall specify the period of warranty together with a list of items covered under the warranty.

3. QUESTIONNAIRE FOR TENDERS

Tender are asked to supply the following information to demonstrate their ability to meet the requirements of the project.

3.1 General Information

Name of Company:-

Individual contact:-

Address, telephone, telex and fax.:-

Legal status (e.g. limited company, etc.):-

Country in which registered and registration numbers:-

Company's financial status (assets & liabilities, last 3 years returns of accounts, etc.):-

Total number of employees:-

3.2 Experience of Tender

Number of years of experience with PV systems:-

Product experience (list some of the systems in use and the total peak power of each main product type eg: pumps, lights, refrigerator, communications, etc.):-

(1)

:

3.3 Source of Supply for Equipment Tendered

Items manufactured by contractor:-

Items bought from suppliers:-

3.4 Maintenance Requirements (details and frequency)

(1)

:

:

3.5 After sales Service

Tender to list names, addresses, telex and telephone number of persons and organisation who may be contacted for advice during the period of installation and operation of the equipment.

4. PRICE AND DELIVERY

Terms of payment .... % on order

.... % on delivery

.... % on satisfactory operation

	Item	Description	Currency	Price
1. Equipment				
2. Transportation				
3. Installation, Labour, etc.				
4. Others				
				......
			Total	
				......

Total Contract Price

4.1 Spare Parts (including prices)

(1)

:

:

:

Delivery of complete system to be within 24 weeks from receipt of order.

PV SYSTEM SUPPLIERS AND ADDRESSES

AFRICA

BP Solar East Africa Ltd
Fedha Tower
Muindi Mbingu St
Nairobi, KENYA
Tel: +254 2 336396
Fax: +254 2 331756

BP Solar Zambia
PO Box 31999
Mutaba House, Cairo Road
Lusaka, ZAMBIA
Tel: +260 1 215390
Tlx: 41180

CDK Engineering Ltd
29 Nassar Road
PO Box 1173
Kampala, UGANDA
Tel: +256 41 259902

FNMA
14me Rue Limete
BP 1967
Kinshasa 1, ZAIRE
Tel: +243 12 77264/23482
Tlx: 22080

Intertec Contracting
(C Africa) ltd
PO Box 409
Blantyre, MALAWI
Tel: 636825
Tlx: 4544 INTEC MI

NOACK Solar International
Gambia Ltd
PO Box 2284, Serrekunda
THE GAMBIA
Tel: +220 96524

NORD Industrie
26 Avenue Kheireddine Pacha
Tunis, TUNISA
Tel: +216 1 288746
Tlx: +14906

Scan African Trading Ltd
PO Box 40490
Gabarone, BOTSWANA
Tel: 313638
Tlx: 2638 SCANT BD

Solarcomm
PO Box ST319
Southerton
Harare, ZIMBABWE
Tel: +263 0 64341
Tlx: 26482

Somafrec
Rue Enseigne Froger
BP 800
Bumako, MALI
Tel: +223 225584
Tlx: 425

VM Solar The Gambia Ltd
Opposite Sir Dawda
Primary School
PMB 38
Banjul, The Gambia
Tel: +220 226947
Fax: +220 226287

West African Batteries
16 Keffi Street
S/W Ikoyi
PO Box 2341
Lagos, NIGERIA
Tel: +234 1 685095
Fax: +234 1 685182

AUSTRALASIA

BP Solar Australia
98 Old Pittwater Road
Brookvale, NSW 2100
AUSTRALIA
Tel: +61 2 938 5111
Fax: +61 2 939 1548

Solarex Pty Ltd
78 Biloela Street 2163
Villawood, PO Box 204
Chester Hill 2162
NSW, AUSTRALIA
Tel: +61 2 727 4455
Fax: +61 2 727 7447

EUROPE

BP Solar Ltd
36 Bridge Street
Leatherhead
Surrey KT22 8BZ, UK
Tel: +44 372 377899
Tlx: 263320 BPSIL
Fax: +44 372 377750

BP Solar Espana
Poligono Industrial de
Valportillo
Calle Primera 5
Alcobendas, Madrid
SPAIN
Tel: +34 1 6534422
Fax: +34 1 6535771

Dulas Engineering
Old School House
Eylwystach, Machynlleth
Wales SY20 8SX, UK
Tel: +44 654 74332
Fax: +44 654 74390

ENE
Avenue Vander Meerschen 108
B-1150, Brussels
BELGIUM
Tel: +32 2 771 13 28

Grundfos
DK-8850, Bjerringbro
DENMARK
Tel: +45 86 68 1400
Tlx: 60731 GFOS DK
Fax: +45 86 68 4472

Helios Technology
Via PO 8
Galliera 1-35015
Veneta (Padova), ITALY
Tel: +39 59 65655
Fax: +39 59 58255

ICPE PV Co.
T Vladimirescu Bd
45-47, 79623 Bucharest
ROMANIA
Tel: +40 0 314100
Tlx: 010486

NAPS Sweden
Stensatravagen
S-127 35 Skarholmen
SWEDEN
Tel: +46 8 979 565
Fax: +46 8 463 205

NAPS Finland
Ralssitie 7
SF-01510 Vantaa
FINLAND
Tel: +358 0 8701611
Fax: +358 0 826 301

Noack Solar
Kjelsaavelen 160
Box 79, Kjelsaas
0411 Oslo 4, NORWAY
Tel: +47 2 227460
Tlx: 71128 NOACK N
Fax: +47 2151808

Photowatt Intnl S.A.
65, Av du Mont Valerien
92500 Rueil-Malmaison
FRANCE
Tel: +47 080505
Tlx: 202084

R&S Renewable Energy System
PO Box 45, 5600AA Eindhoven
THE NETHERLANDS
Tel: +31 40 520155
Tlx: 59030 RES NL
Fax: +31 40 550625

Siemens Solar GmbH
Buchenallee 3
D-5060, Bergisch Gladbach
GERMANY
Tel: 49 89 3500
Tlx: 884 891 SSOL
Fax: 49 89 35002573

Textronica
Av. Colegio Militare 153-B
1500 Lisboa
PORTUGAL
Tel: +351 1 715 5684
Fax: +351 1 715 2123

Transelektro
1394 Budapest
P O B 377
HUNGARY
Tlx: 224571

VIESH
1st Veschnjakovskij Str, 2
109456 Moscow
USSR

Vergnet SA
66, Rue Hoche
92240 Malakoff
FRANCE
Tel: +33 1 474 61616
Fax: +33 1 474 60686

WINDSOL
18 Chatzopoulou St
17671 Kallithea
GREECE
Tel: +30 9232943
Tlx: 226551

<u>ASIA</u>

HMA Investment Ltd
11 West Wharf Road
PO Box 5266
Karachi 2, PAKISTAN
Tel: 202737
Tlx: 25499 HMAI PLC

Tata-BP Solar
A101 Block 11
KSSIDC Multistorey Blocks
Electronic City, Hebbagodi
Hosur Road Bangalore 562158
INDIA
Tlx: 8408 224
Fax: +91 8114 2417

AWA Ltd
47 Forster Road
Walu Bay, Suva
FIJI

BP Solar Malaysia
37th Floor, Menara Maybank
100 Jalan Tun Pesak
50734 Kuala Lumpur
MALAYSIA
Tel: +60 3 232 6322
Fax: +60 3 232 7642

BP Solar Papua New Guinea
PO Box 569
Speybank Street, Lae
PAPUA NEW GUINEA
Tel: +675 422200
Fax: +675 424401

BP Thai Solar Corporation
Corporation Ltd, 13th Floor
Sitthivorakil Building
5, Soi Pipat, Silom Road
Bangkok, THAILAND
Tel: +66 2 2368160
Fax: +66 2 2368169

China PV Centre
91 Huang Cheng Xi Lu Road
Hangzhou, CHINA P.R.
Tlx: 35069

NAPS East Asia
Room 808 Wingon Plaza
62 Mody Road
Tsimshatsui E., Kowloon
Hong Kong
Tel: +852 739 6565
Fax: +852 311 5289

Solarindo
PT Centronix
Jl Matraman Raya 36
Jakarta 13150
INDONESIA
Tel: +62 21 884187
Tlx: 48216

Showa Arco Solar
10 Anson Road 18-24
International Plaza
SINGAPORE 0207
Tel: 2212 433
Tlx: RS 20061 ASIS PR
Fax: 22 58002

Solar Lab
Trung Tam Vat Ly
01 Mac Dinh Chi, Q1.TP
Ho Chi Minh City
VIETNAM
Tel: 22028

BP Solar Arabia
PO Box 85652
Riyandh 11612
SAUDI ARABIA
Tel: +966 1 498 4864
Fax: +966 1 498 4796

Grundfos Gulf
Jebei Ali Free Port
Dubai, UAE
Tel: +84 55166
Fax: +84 55135

Mitsuibishi Electric
2-3 Marunouchi
2-Cho, Chiyoda-Ku
Tokyo 100, JAPAN
Tel: 031 218 3535
Tlx: 24532

USA AND CANADA

Siemens Solar Inc
PO Box 6032, Camarillo
CA 93010, USA
Tel: +1 805 388 6335
Tlx: 6716260

Solarex Corporation
1335 Piccard Drive
Rockville, MD 20850
USA
Tel: +1 301 948 0202
Tlx: 64358
Fax: +1 301 948 7148

Solar Engineering Ltd
1210 Homann Drive SE
Lacey, WA 98503
USA
Tel: +1 206 438 2110
Fax: +1 206 438 2115

Intersolar Group Canada
4044 Aberdeen Road
Beamsville, Ontario
LOR 1B6, CANADA
Fax: +1 416 563 0539

CENTRAL AND SOUTH AMERICA

BP Solar
Apartado Aereo 59824
Bogota, COLOMBIA
Tel: +57 1 218 3029
Tlx: 45822 BPCO

Heliodinamica
Rodovia Raposa Tavares
KM 41, Caixa Postal 111
06730 Vargem Grande
Paulista (SP)
BRAZIL
Tel: +55 11 790 0888
Fax: +55 11 790 1280

Repprice
Calle 13 Etre Carrera 23Y
24 No. 23-66 Barquisimetro
VENEZUELA
Tel: +58 51 51250
Fax: +58 51 518016

Enerssin
PO Box 90880
Bogota
COLOMBIA

APPENDIX 4.

LIST OF PUBLICATIONS.

(1) U. Able-Thomas, R. Hill and N.M. Pearsall, "A Model for PV dissemination in the Gambia", Proc. 11th European Photovoltaic Solar Energy Conference, Montreux, October 1992, pp1526-9, Harwood Academic Publishers, Switzerland (1993).

(2) U. Able-Thomas, R. Hill, P. O'Keefe, N.M. Pearsall and A. Derrick, "Marketing Strategies for PV Dissemination in The Gambia", Proc. 12th European Photovoltaic Solar Energy Conference, Amsterdam, April 1994, pp2041-4, H.S. Stephens and Associates, UK, (1994).

(3) U. Able-Thomas, R. Hill, P. O'Keefe and N.M. Pearsall, "Cost Effectiveness & Benefits of PV in The Gambia", Proc. World Renewable Energy Congress - III, Reading, U.K., September 1994, vol.1, pp247-9, Pergamon Press Limited Publication, UK, (1994).

(4) U. Able-Thomas, R. Hill, P. O'Keefe and N.M. Pearsall, "Dissemination of Photovoltaics in The Gambia", Proc. International Conference on Solar Electricity: Photovoltaics and Wind, Cairo, Egypt, October 1994.